PB-233 630

PROGRAM FOR THE MANAGEMENT OF HAZARDOUS WASTES

VOLUME 1

Battelle Memorial Institute

PREPARED FOR
Environmental Protection Agency

1974

DISTRIBUTED BY:
NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

BIBLIOGRAPHIC DATA SHEET

1. Report No. EPA530/SW54c-1

2. 191007

PB 233 630

4. Title and Subtitle

PROGRAM FOR THE MANAGEMENT OF HAZARDOUS WASTES (VOL One)

1974

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Battelle Memorial Institute

10. Project/Task/Work Unit No.

11. Contract/Grant No.

68-01-0762

12. Sponsoring Organization Name and Address

U.S. Environmental Protection Agency
Office of Solid Waste Management Programs
Washington, D.C. 20460

13. Type of Report & Period Covered

Final

14.

15. Supplementary Notes

16. Abstracts

The report contains data, analysis, and rationale that define and identify hazardous waste streams according to industry classification and by hazardous constituents. A priority ranking system is proposed which may be employed to develop a priority-of-concern list of hazardous wastes. Site-types are identified; process selection and design concepts are described and include system flow diagrams and various sub-systems (e.g. liquids-solids separation module, resource recovery, and effluent monitoring); issues of transportation of hazardous wastes are described; and detailed cost estimates for "small", "medium", and "large" site-types are developed.

17. Key Words and Document Analysis. 17a. Descriptors

hazardous materials
industrial waste treatment
material recovery
radioactive wastes
radioactive waste processing
waste disposal

17b. Identifiers/Open-Ended Terms

disposal facilities
hazardous compounds
hazardous waste disposal
hazardous waste management
processing facilities
resource recovery

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
397

22. Price
$8.25

FORM NTIS-35 (10-70)

USCOMM-DC

PROGRAM

FOR THE MANAGEMENT OF HAZARDOUS WASTES

Volume One of Two Volumes

This final report (SW-54c) describing work performed
for the Federal solid waste management program
under Contract No.68-01-0762
by BATTELLE MEMORIAL INSTITUTE
is reproduced as received from the contractor

U.S. ENVIRONMENTAL PROTECTION AGENCY
1974

This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of commercial products constitute endorsement or recommendation for use by the U.S. Government.

An environmental protection publication (SW-54c) in the solid waste management series

PREFACE AND ACKNOWLEDGMENTS

This report has been prepared by Battelle Memorial Institute, Pacific Northwest Laboratories over the period September 1, 1972 to March 1, 1973 under Contract No. 68-01-0762 with the Office of Solid Waste Management Programs.

Assistance was provided by a number of the Battelle-Columbus staff including G. S. Stacey, N. L. Drobny, J. E. Flinn, H. Nack, D. E. Manty, P. W. Lerro, K. M. Duke, J. S. Lawson, and J. L. Moore. Mr. J. Dowd of Squire, Sanders & Dempsey, Cincinnati, Ohio, provided input in the review of legislation. Assistance was also obtained under subcontract from the Dow Chemical Company (Dr. James P. Flynn) of Midland, Michigan, and from Envisors Inc. (Mr. R. D. Vaughan and Dr. C. J. Touhill) of Rockville, Maryland. The contributions from all are gratefully acknowledged.

In addition to independent work, material has been drawn from prior and concurrent work conducted by Booz-Allen Applied Research, TRW Systems Group, and Arthur D. Little, Inc., also under contract to the Office of Solid Waste Management Programs.

Battelle-Northwest staff participating included G. W. Dawson, J. G. Droppo, the late W. A. Haney, P. L. Hendrickson, G. Jansen, B. W. Mercer, D. F. Newman, G. F. Schiefelbein, K. J. Schneider, A. J. Shuckrow, D. D. Tillson, and W. K. Winegardner. W. H. Swift served as program manager.

The secretarial efforts of Ms. Bobbi Lyons, Shirley Rose, Chris Jacobsen, Sheree Whitten, Jan Greenwell, Loretta Howard, Diane Larson, Velva Harris, Charlene Miller and Dee Parks are greatfully acknowledged. Ms. Leila Counts served as Technical Editor.

Special thanks must go to various members of the Office of Solid Waste Management Programs. Mr. Sam Morekas, project officer, and Mr. Don Marlow, project monitor, provided very helpful guidance throughout the program.

TABLE OF CONTENTS

Page No.

Chapter I - BACKGROUND AND INTRODUCTION

Chapter Contents 1
The Resource Recovery Act of 1970--Public Law 91-512, Section 212 3
Congressional Intent and the Establishment of a National Goal 3
Issues and Variables Involved in the Problem 4
  Technical Issues 4
  Economic Issues 9
  Implementation and Administrative Issues 11
Framework of Evaluation 13

Chapter II - SUMMARY AND CONCLUSIONS

Chapter Contents 15
Identification and Designation of Hazardous Wastes 17
Waste Management Methods and Costs 18
Radioactive Wastes 21
Siting Considerations 23
Implementation 24

Chapter III - DEFINITION AND IDENTIFICATION OF HAZARDOUS WASTES

Chapter Contents 26
Brief 29
Definition of Hazardous Wastes 30
  Hazards of Concern 31
Existing Definitions of Hazardous Materials 35
  The Pure Compound Approach 36
  The Hazardous Waste Decision Model 42
  Application of Model to Waste Streams 53
Inventory of Hazardous Wastes 54
Department of Defense Wastes 64
  Biological, Chemical, and Explosive Wastes 66
Priority of Concern 73

Chapter IV - HAZARDOUS WASTE MANAGEMENT METHODS AND COSTS

Chapter Contents 81
Brief 83
Description of Site Types 84
  Hazardous Waste Processing Facility 84
  Hazardous Waste Disposal Facility 85

Preceding page blank

TABLE OF CONTENTS (Continued)

Page No.

Chapter IV (Continued)
- Process Selection 85
  - Potential Processes 85
  - Selected Processes 85
  - Treatment and Disposal 88
- Process Design 91
  - Treatment Facility 91
  - Receiving, Segregation, and Storage Module 93
  - Ammonia Stripping Module 95
  - Chemical Treatment Module 101
- Liquids-Solids Separation Module 107
  - Carbon Sorption Module 115
  - Incinerator Module 115
  - Evaporation Module 118
- Landfills 118
- Brine Disposal 123
- Process Performance Levels 124
- Resource Recovery 124
  - Candidate Recovery Materials 127
  - Reprocessing 134
  - Fuel for Evaporation/Concentration of Aqueous Wastes 134
  - Fuel for Boiler Plant 135
- Effluent Monitoring 135
- Transportation of Wastes for Processing 137
  - Cost Estimates 138

Chapter V - RADIOACTIVE WASTES
- Chapter Contents 147
- Brief 151
- Findings and Conclusions for Radioactive Wastes 151
- Background of Radioactive Waste Management Policies and Radiation Protection Regulations in the U.S. 157
  - Overall Legislative History 157
  - General Dose and Effluent Considerations 159
  - Disposal or Long-Term Storage of Wastes 161
  - Administrative Arrangements 161
  - Federal Regulation and Control 162
  - State Regulation and Control 164
- Radioactive Wastes and a National System for Hazardous Waste Management 165
- Categories of Radioactive Wastes in a National Disposal System 167

TABLE OF CONTENTS (Continued)

Page No.

Chapter V (Continued)

- Potential Radiological Toxicities Associated With Radioactive Wastes 168
- Sources of Radioactive Wastes 168
- Radioactive Wastes from the Commercial Nuclear Power Industry 170
- Quantities, Constituents, Distribution 171
- Prospective Wastes from the Nuclear Fuel Cycle 171
- Radioactive Wastes from Miscellaneous Private Sources 181
- Radioactive Wastes from Government Sources 183
  - Atomic Energy Commission Sources 183
  - Distribution and Types of Wastes 184
  - Department of Defense Sources 196
- Transportation of Radioactive Wastes 199
  - Regulations for Transportation of Radioactive Wastes 199
  - Transportation Safety Requirements 200
  - Bases for Transportation System Requirements 200
  - Design of Transportation Systems for Radioactive Wastes--Containers and Protection 201
- Radioactive Waste Management System Design 205
  - Bases for Radioactive Waste Disposal 205
  - Types and Quantities of Radioactive Wastes 207
  - High-Level Radioactive Waste--Strategy of Disposal 210
  - Criteria and General Description for Retrievable High-Level Radioactive Waste Repository 214
  - Transportation Costs for High-Level Radioactive Wastes 225
- Low-Level Radioactive Wastes 228
  - Strategy for Disposal of Low-Level Radioactive Wastes 229
  - Criteria and General Description for Retrievable Low-Level Radioactive Waste Storage System 232
  - Transportation Costs for Low-Level Radioactive Wastes 244

Chapter VI - SITING OF HAZARDOUS WASTE PROCESSING AND DISPOSAL FACILITIES

- Chapter Contents 249
- Brief 251
- Goals and Objectives of Site Selection 255
- Health, Safety and Environmental Considerations 256

TABLE OF CONTENTS (Continued)

Page No.

Chapter VI (Continued)

Development of Site Selection Criteria 257
Earth Sciences 258
Geological Criteria 258
Hydrological Criteria 260
Soil Criteria 261
Climatological Criteria 263
Transportation 265
Ecology 267
Human Environment and Resources Utilization 269
Site Screening Procedures 271
Area Size Determination 272
Information Sources 272
Regional Divisions 273
Ranking and Weighing Systems--Development and Application 276
Characteristics and Locations of Existing and Potential Sites 279
Existing and Potential Hazardous Waste Sites 282
Site Monitoring Requirements 283
Evaluation and Extension of the Rating System 285
Siting Considerations as Related to Disposal Methods 286
Deep-Well Injection of Brines 286
Land Burial Disposal 291
Ocean Disposal of Hazardous Waste Materials 296
Conclusions 303

Chapter VII - IMPLEMENTATION

Chapter Contents 305
Brief 309
Institutional Alternatives 311
Discussion of Alternatives 312
Alternative One: No Change in Existing System 312
Alternative Two: State Responsibility and Standards 313
Alternative Three: State Responsibility and Standards with Federal Subsidy to Finance State or Locally Operated Systems 314
Alternative Four: State Responsibility and Standards with Federal Tax Incentives to Encourage Satisfactory Hazardous Wastes Management 314
Alternative Five: State Responsibility with Standards Meeting Federal Guidelines 315

TABLE OF CONTENTS (Continued)

Page No.

Chapter VII (Continued)

Alternative Six: State Responsibility and Standards Meeting Federal Guidelinew with Federal Subsidy to Finance State or Locally Operated Systems 317
Alternative Seven: Federal Responsibility and Standards with No Management System 318
Alternative Eight: Federal Responsibility and Standards with Federal Subsidy to Finance State or Locally Operated Systems 319
Alternative Nine: Federal Responsibility and Standards with No Management System but with Federal Tax Incentives to Encourage Satisfactory Waste Management 320
Alternative Ten: Federal Responsibility and Standards with Private Facility Ownership Operating Under State Licensing and Enforcement 321
Alternative Eleven: Federal Responsibility, Standards, and Facility Ownership, with Operation by Private Enterprise Under Federal Contract 322
Alternative Twelve: Federal Responsibility, Facility Ownership, and Operation 323
Institutional Alternatives Matrix 324
Summary and Conclusions 327
Legislative Review - State Legislation/Regulations 327
Federal Legislation/Regulations 329
Substantive Aspects 332
Legislative References 339
Recent Legislation 340
Transportation Aspects 341
Inadequacies of the Present Federal System of Controlling Transportation of Hazardous Wastes in Interstate Commerce 346
Summary 350
Policy-Making 350
Financing Considerations 352

Chapter VIII - REFERENCES 353

LIST OF FIGURES

Page No.

FIGURE 1 GRAPHIC REPRESENTATION OF THE HAZARDOUS WASTE DECISION MODEL 43

FIGURE 2 CONCEPTUAL MODULAR FLOW DIAGRAM 92

FIGURE 3 WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF LIQUID AQUEOUS WASTES 96

FIGURE 4 WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF ORGANIC SOLIDS, SLUDGES, SLURRIES, AND SOLUTIONS 97

FIGURE 5 WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF CYANIDE FREE, INORGANIC SOLIDS, SLUDGES, AND SLURRIES 98

FIGURE 6 WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF CYANIDE RICH, INORGANIC SOLIDS, SLUDGES, AND SLURRIES 99

FIGURE 7 WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE CONCEPTUAL FLOW SCHEMATIC FOR C-5 AQUEOUS ORGANIC CONTAINING-WASTE STREAMS 100

FIGURE 8 CONCEPTUAL FLOW SCHEMATIC OF AMMONIA STRIPPER MODULE 102

FIGURE 9 CHEMICAL TREATMENT MODULE CONCEPTUAL FLOW SCHEMATIC FOR REDUCTION AND PRIMARY PRECIPITATION 103

FIGURE 10 CHEMICAL TREATMENT MODULE CONCEPTUAL FLOW SCHEMATIC FOR OXIDATION AND SECONDARY PRECIPITATION 105

LIST OF FIGURES (Continued)

Page No.

FIGURE 11 108
CHEMICAL TREATMENT MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF LIME AND POLYELECTROLYTE

FIGURE 12 109
CHEMICAL TREATMENT MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF NITROGEN, SULFUR DIOXIDE, AND CHLORINE

FIGURE 13 110
CHEMICAL TREATMENT MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF HYDROCHLORIC ACID AND SODIUM SULFIDE

FIGURE 14 111
LIQUID-SOLIDS SEPARATION MODULE CONCEPTUAL FLOW SCHEMATIC FOR PRIMARY CLARIFICATION AND SLUDGE FILTRATION

FIGURE 15 112
LIQUID-SOLIDS SEPARATION MODULE CONCEPTUAL FLOW DIAGRAM FOR SECONDARY CLARIFICATION AND SLUDGE FILTRATION

FIGURE 16 113
LIQUID-SOLIDS SEPARATION MODULE CONCEPTUAL FLOW SCHEMATIC FOR CLARIFICATION OF INCINERATOR SCRUBBER WATER AND FILTRATION OF ASH SLUDGE

FIGURE 17 114
LIQUID-SOLIDS SEPARATION MODULE CONCEPTUAL FLOW SCHEMATIC FOR BRINE FILTRATION

FIGURE 18 116
CONCEPTUAL FLOW SCHEMATIC FOR CARBON SORPTION MODULE

FIGURE 19 117
INCINERATION MODULE CONCEPTUAL FLOW SCHEMATIC OF INCINERATION SYSTEM

FIGURE 20 119
CONCEPTUAL SCHEMATIC OF SUBMERGED COMBUSTION EVAPORATOR

LIST OF FIGURES (Continued)

Page No.

FIGURE 21 122
CONCEPTUAL SCHEMATIC OF SECURED LANDFILL

FIGURE 22 125
CONCEPTUAL SCHEMATIC OF INJECTION WELL

FIGURE 23 129
FLOW DIAGRAM OF THE RECOMMENDED METAL RECOVERY SCHEME FROM METAL-FINISHING WASTES

FIGURE 24 132
SCHEMATIC OF SOLVENT RECOVERY PROCESS

FIGURE 25 143
RAIL AND BARGE SHIPMENT COSTS AS A FUNCTION OF DISTANCE

FIGURE 26 212
HEAT GENERATION RATE OF HIGH-LEVEL RADIOACTIVE WASTES FROM A TYPICAL LIGHT WATER REACTOR AS A FUNCTION OF TIME AFTER DISCHARGE

FIGURE 27 213
TYPICAL CANISTER FOR HIGH-LEVEL RADIOACTIVE WASTES

FIGURE 28 216
ACTIVITIES IN A RETRIEVABLE SURFACE STORAGE FACILITY FOR HIGH-LEVEL RADIOACTIVE WASTES

FIGURE 29 217
WATER BASIN CONCEPT FOR RETRIEVABLE SURFACE STORAGE FACILITY FOR HIGH-LEVEL RADIOACTIVE WASTES

FIGURE 30 220
LAYOUT OF WATER STORAGE BASIN FOR RETRIEVABLE SURFACE STORAGE FACILITY FOR HIGH-LEVEL RADIOACTIVE WASTES

FIGURE 31 221
BASIN WATER PROCESS FLOW DIAGRAM FOR RETRIEVABLE SURFACE STORAGE FACILITY FOR HIGH-LEVEL RADIOACTIVE WASTES

LIST OF FIGURES (Continued)

Page No.

FIGURE 32 224
SEALED STORAGE CASK CONCEPT FOR RETRIEVABLE SURFACE STORAGE OF HIGH-LEVEL RADIOACTIVE WASTES

FIGURE 33 235
LOW-LEVEL RADIOACTIVE WASTE PROCESSING AND STORAGE FACILITY

FIGURE 34 238
OVERALL LAYOUT OF LOW-LEVEL RADIOACTIVE WASTE STORAGE FACILITY

FIGURE 35 275
SITE SELECTION REGIONS

FIGURE 36 281
SEISMIC PROBABILITY MAP

FIGURE 37 287
DEEP WELL DISPOSAL SITES

FIGURE 38 300
PACIFIC COAST DISPOSAL AREAS

FIGURE 39 301
ATLANTIC COAST DISPOSAL AREAS

FIGURE 40 302
GULF OF MEXICO DISPOSAL AREAS

LIST OF TABLES

Page No.

TABLE 1
POSSIBLE CLASSIFICATION SYSTEM CRITERIA FOR CATEGORIZATION OF HAZARDOUS MATERIALS 37

TABLE 2
NONRADIOACTIVE HAZARDOUS COMPOUNDS EMPLOYED FOR PURE COMPOUND SELECTION PROCEDURE 40

TABLE 3
LIMITING DOSAGES DIFFERENTIATING TOXIC AND NONTOXIC SUBSTANCES ACCORDING TO ROUTE OF ADMINISTRATION TO EXPERIMENTAL ANIMALS OF A MAXIMUM SINGLE (ACUTE) DOSE CAUSING DEATH 49

TABLE 4
SUMMARY DATA FOR NONRADIOACTIVE WASTE STREAMS 58

TABLE 5
REGIONAL SUMMARY DATA FOR TOTAL QUANTITY OF NONRADIOACTIVE HAZARDOUS WASTES 65

TABLE 6
LOCATIONS AND AMOUNTS OF HAZARDOUS MATERIALS PRESENTLY STORED AT MILITARY ARSENALS 68

TABLE 7
COMPOSITION OF SALT RESIDUES FROM DEMILITARIZATION OPERATIONS 70

TABLE 8
OBSOLETE CONVENTIONAL MUNITIONS HAZARDOUS MATERIAL CONTENTS AND GROSS WEIGHT DISTRIBUTION BY STATE--SCHEDULED FOR DISPOSAL BY THE DEPARTMENT OF DEFENSE 72

TABLE 9
EXPLOSIVE MANUFACTURING WASTES - POUNDS PER YEAR SOLID WASTE 74

TABLE 10
CLASSIFICATION OF WASTE DISPOSAL/RECOVERY PROCESSES AS DEVELOPED BY TRW 86

LIST OF TABLES (Continued)

Page No.

TABLE 11 — 87
WASTE DISPOSAL/RECOVERY PROCESSES SELECTED FOR APPLICATION TO HAZARDOUS WASTE TREATMENT AS SPECIFIED BY TRW

TABLE 12 — 89
PROCESSES SELECTED FOR INCLUSION IN MODEL HAZARDOUS WASTE PROCESSING/DISPOSAL FACILITY

TABLE 13 — 126
BEST CURRENTLY EXISTING PERFORMANCE LEVELS FOR BRINE WASTES

TABLE 14 — 131
TYPES, PROPERTIES, AND QUANTITIES OF SOLVENTS ESTIMATED TO BE AVAILABLE FOR RECOVERY

TABLE 15 — 139
PRELIMINARY COST ESTIMATE SUMMARY FOR MEDIUM SIZE PROCESSING FACILITY

TABLE 16 — 140
PRELIMINARY COST ESTIMATE SUMMARY FOR SMALL SIZE PROCESSING FACILITY

TABLE 17 — 141
PRELIMINARY COST ESTIMATE SUMMARY FOR LARGE SIZE PROCESSING FACILITY

TABLE 18 — 146
ANNUAL OPERATING COSTS FOR A MEDIUM AND A LARGE TREATMENT FACILITY

TABLE 19 — 153
SUMMARY OF RADIOACTIVE WASTES FOR DISPOSAL IN 1980

TABLE 20 — 166
STATE REGULATIONS FOR RADIOACTIVE WASTE DISPOSAL

TABLE 21 — 172
SUMMARY OF RADIOACTIVE WASTES FROM COMMERCIAL NUCLEAR POWER INDUSTRY TO BE PRODUCED IN 1980

LIST OF TABLES (Continued)

Page No.

TABLE 22 SUMMARY OF GEOGRAPHIC DISTRIBUTION OF RADIOACTIVE WASTES FROM COMMERCIAL NUCLEAR POWER INDUSTRY IN 1980 (FRACTION OF RADIOACTIVITY IN EACH REGION, $T \overset{-}{<} 0.05$) 175

TABLE 23 PROSPECTIVE WASTE STREAMS FOR NATIONAL DISPOSAL SITES FROM COMMERCIAL NUCLEAR POWER INDUSTRY IN 1980 176

TABLE 24 ESTIMATED RADIOISOTOPE DISPOSAL FROM MISCELLANEOUS PRIVATE SOURCES 182

TABLE 25 IDENTIFICATION OF MAJOR AEC SITES PRODUCING RADIOACTIVE WASTES 185

TABLE 26 QUALITATIVE INDICES TO TYPES OF RADIOACTIVE WASTES HANDLED AT AEC SITES 187

TABLE 27 QUANTITIES OF RADIOACTIVE WASTES HANDLED PER YEAR AT AEC SITES 190

TABLE 28 ESTIMATED BACKLOG OF SOLID RADIOACTIVE WASTES AT VARIOUS AEC BURIAL GROUNDS 192

TABLE 29 ESTIMATED PLUTONIUM CONTENT OF ACCUMULATED RADIOACTIVE WASTES AT AEC SITES (AS OF END OF FY 1972) 194

TABLE 30 TYPICAL LOW-LEVEL RADIOACTIVE WASTE DESCRIPTION 197

TABLE 31 RADIOACTIVE SOLID WASTE FROM U.S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES FOR 1966 THROUGH 1970 198

TABLE 32 AVERAGE ONE-WAY DISTANCES BETWEEN SOURCES AND DISPOSAL SITES FOR RADIOACTIVE WASTES 204

LIST OF TABLES (Continued)

Page No.

TABLE 33 PRELIMINARY ESTIMATE OF TOTAL COST FOR HIGH-LEVEL RADIOACTIVE WASTE RETRIEVABLE SURFACE STORAGE FACILITY 226

TABLE 34 INCINERATOR COSTS AT LOW-LEVEL RADIOACTIVE WASTE STORAGE FACILITY FOR 1980 THROUGHPUT 231

TABLE 35 CAPITAL AND OPERATING COSTS FOR LOW-LEVEL WASTE RETRIEVABLE SURFACE STORAGE FACILITY 243

TABLE 36 1973 OPERATING COSTS FOR TRANSPORTATION OF LOW-LEVEL RADIOACTIVE WASTES IN 1980 246

TABLE 37 INDUSTRIAL WASTE PRODUCTION CENTERS 253

TABLE 38 MARINE DISPOSAL AREAS FOR HAZARDOUS WASTES (BY REGION AND WASTE TYPE) 298

TABLE 39 INSTITUTIONAL ALTERNATIVE MATRIX 325

TABLE 40 SUMMARY OF STATE LEGISLATION SURVEY 330

CHAPTER CONTENTS

CHAPTER I

BACKGROUND AND INTRODUCTION

Page No.

THE RESOURCE RECOVERY ACT OF 1970--PUBLIC LAW 91-512, SECTION 212 3

CONGRESSIONAL INTENT AND THE ESTABLISHMENT OF A NATIONAL GOAL 3

ISSUES AND VARIABLES INVOLVED IN THE PROBLEM 4

Technical Issues 4

- Definition and Designation 5
- Wastes as Mixtures 5
- Multiplicity of Sources 5
- Time Dependence of Quantities and Nature 6
- Different Types of Hazards 6
- Sophistication Level Involved 6
- Waste Management System Elements and Methods 7
- Siting of Hazardous Waste Processing and Disposal Operations 7
- Standards and Measures of Performance 8
- Priorities 8
- Information Needs 9

Economic Issues 9

- Management System Cost 9
- Equitable Distribution of Burden 10
- Maintenance of Competition 10
- Cost of Perpetual Care 10
- Public Sector Financial Involvement 10
- Availability of Private Sector Capital 11
- Resource Recovery Potential 11

Implementation and Administrative Issues 11

- Implementation Options 11
- Effectiveness of the System 11
- Federal Cost and Employment 12
- Legislative Requirements 12

CHAPTER CONTENTS (Continued)

Page No.

Compatibility with Environmental Protection Programs as a Whole 13
Private Sector Involvement 13

FRAMEWORK OF EVALUATION 13

CHAPTER I

BACKGROUND AND INTRODUCTION

THE RESOURCE RECOVERY ACT OF 1970--PUBLIC LAW 91-512, SECTION 212

In October 1970 the Congress enacted Public Law 91-512, The Resource Recovery Act of 1970. Section 212 of this Act calls for a feasibility study for a system of national hazardous waste disposal sites. The Congress specifically directed that:

> *The Secretary* shall submit to the Congress no later than two years after the date of enactment of the Resource Recovery Act of 1970, a comprehensive report and plan for the creation of a system of national disposal sites for the storage and disposal of hazardous wastes, including radioactive, toxic chemical, biological, and other wastes which may endanger public health or welfare. Such report shall include: (1) a list of materials which should be subject to disposal in any such site; (2) current methods of disposal of such materials; (3) recommended methods of reduction, neutralization, recovery, or disposal of such materials; (4) an inventory of possible sites including existing land or water disposal sites operated or licensed by Federal agencies; (5) an estimate of the cost of developing and maintaining sites including consideration of means for distributing the short- and long-term costs of operating such sites among the users thereof; and (6) such other information as may be appropriate.*

CONGRESSIONAL INTENT AND THE ESTABLISHMENT OF A NATIONAL GOAL

In reviewing the letter and spirit[1] of Section 212 of the Resource Recovery Act and related subsequent legislation,[2,3,4] the Environmental Protection Agency recognized several common elements of Congressional concern.

---

*Under the Reorganization Plan No. 3 of 1970, responsibility for carrying out the provisions of the Resource Recovery Act was assigned to the Administrator of the Environmental Protection Agency.

1. Hazardous materials and wastes, regardless of origin, represent a substantial and growing threat to public health and environmental quality.

2. Management of such wastes is presently inadequate and the need for responsible stewardship will increase in the future.

3. The problems posed in the management of hazardous wastes do not necessarily recognize state boundaries, and the materials in question derive from a variety of sources, both private and public; therefore, consideration should be given to the feasibility of establishing a national system of disposal sites. The Congress[1] has indicated

   > *...that further information is needed on the desirability and feasibility of a system of solid waste disposal sites for hazardous materials.*

Considered in their entirety, the elements enumerated above call for the establishment of a national goal:

> In order to protect the public health and welfare and the quality of the environment, present practices in disposal of hazardous waste materials must be significantly improved, and a framework for responsible stewardship established.

ISSUES AND VARIABLES INVOLVED IN THE PROBLEM

In assessing the goal stated above and the means available for achieving it, the Environmental Protection Agency found that a wide range of issues and variables are involved, including:

- Technical Issues
- Economics Issues
- Implementation and Administrative Issues

To a large degree, these areas are interwoven and must be considered in the context of the whole. Nevertheless, it is useful to briefly discuss them separately in an effort to more carefully define the scope and nature of available options. A more thorough discussion of each issue is given in the following pages of this report.

Technical Issues

The technical issues involve definitions of the nature and magnitude of the problems to be solved and the approaches which can be used; that is, the technical issues are the basic physical "what" and "how" of the system.

Definition and Designation

Section 212 of Public Law 91-512 speaks of

> *... radioactive, toxic chemical, biological, and other ...*

This designation is adequate for framing a broad goal but lacks the detail necessary for bounding the problem and arriving at solutions. A more precise definition is suggested;

> The term "hazardous waste" means any waste or combination of wastes which pose a substantial present or potential hazard to human health or living organisms because such wastes are lethal, nondegradable, persistent in nature, biologically magnified, or otherwise cause or tend to cause detrimental cumulative effects. General categories of hazardous waste are toxic chemical, flammable, radioactive, explosive and biological. These wastes can take the form of solids, sludges, liquids, or gases.

Even this definition, however, fails to specify and quantify the elements of the inherently relative term hazardous. Therefore, a rational and consistent system for the designation of hazardous wastes has been developed for the purposes of this study and is discussed in detail in Chapter III.

Wastes as Mixtures

By far the majority of waste materials and streams are mixtures, and hazardous wastes are no exception. In terms of quantity, the hazardous constituents may be a very minor portion of the total waste. Thus management techniques, in both processing and disposal, may be controlled as much by the nonhazardous materials as by the hazardous constituents. The presence of nonhazardous constituents may also markedly effect the behavior of trace hazardous constituents.

Thus the issue of hazardous wastes as mixtures has relevance to both their designation and to their management. This is further discussed in Chapters III, IV and V.

Multiplicity of Sources

Hazardous wastes in the United States are generated by both the public and private sectors and the sources are widely distributed geographically. The majority of hazardous wastes are produced by industry and occur in approximate proportion to population density. Sources in the public sector (e.g., the U.S. Atomic Energy Commission and Department of Defense) tend to be more concentrated and localized. Whether private or public, however, waste sources vary widely in size and occur in every state, at locations of industrial production activities and at points of consumption.

Time Dependence of Quantities and Nature

Waste quantities, makeup, and compositions vary with time either gradually or as step functions. A number of factors can affect the rate and direction of change. For example, application of air and water pollution control regulations can be expected to result in greater demands for disposal to land; application of these same regulations may produce economic shifts that will influence the continuance or abandonment of industrial processes which currently produce hazardous wastes and may result in the adoption of new technologies that avoid or circumvent waste production. On the other hand, growth in application of certain new technologies such as nuclear energy production will give rise to increasing problems in other sectors.

Thus it is essential to recognize that regardless of the means adopted for solving the problems associated with hazardous wastes, new and different problems will eventually arise, and one measure of the effectiveness of any program will be its ability to accommodate change.

Different Types of Hazards

In addition to viewing a hazard specifically as either a threat to public health and welfare or to the whole environment, it must be recognized that hazards can be manifest in distinctly different modes and the units of measurement of hazard levels are not necessarily the same.

For example, it is extremely difficult to quantitatively compare the hazard level of an explosive or flammable material to that of a toxic material--the probability of occurrence and extent of effects are too dependent upon the circumstances involved.

Sophistication Level Involved

Hazardous wastes require a markedly higher level of technical knowledge and management control than do ordinary wastes. For purposes of perspective, it is expected that the level of sophistication involved will be comparable to that employed in a diverse chemical manufacturing and processing operation.

Major elements will be quality and performance control and operational safety.

Waste Management System Elements and Methods

A hazardous waste management system, considered from the point of generation to the point of ultimate disposition, can potentially include a number of elements:

1. collection, concentration, and storage of wastes at point of origin;
2. processing--destruction, inerting, detoxification, or isolation at site of origin;
3. transport of hazardous wastes to a separate processing site;
4. processing (as in 2) at separate processing sites;
5. transport of hazardous residues;
6. disposition of hazardous residues; and
7. disposition of nonhazardous bulk residuals.

In this program the elements of special importance pertain to hazardous wastes processing (2 and 4 above) and disposition of residuals (6 and 7). Discussion of these elements will take place in Chapters IV and V. In general, the other elements listed above do not present special technical problems or are a matter of common practice and experience. It should be noted, however, that hazardous wastes are not technically covered by most transportation regulations; furthermore, because of the decreased value of the waste hazardous material, it is believed that without regulation even less care would be exercised in transporting such material.

Siting of Hazardous Waste Processing and Disposal Operations

A number of factors are involved in considering siting of processing and disposal facilities:

1. proximity to points of origin of hazardous wastes in order to reduce the cost and some incremental risk in transportation;
2. isolation from populous areas in order to prevent public exposure to a threat (this may be antithetical to 1 above);

3. the earth sciences aspects of potential sites as they influence design or performance of the facilities (i.e., geology, hydrology, seismicity, flood potential, and meteorology); and

4. relationship to alternative land uses.

Since the term "hazardous wastes" has the connotation of threat, the natural tendency is to suggest siting such facilities as far from the populace as possible. Hazardous wastes, however, with few exceptions, do not in reality present threats significantly greater than many more prevalent articles of commerce, provided that management practices--processing, handling and ultimate disposal--are appropriately designed and carried out. This is particularly true of waste processing facilities where the hazard inventory at any one time is relatively low and engineered safeguards can provide the necessary level of isolation and control.

The case of ultimate hazardous wastes disposal sites, however, is a different matter. The inventory of hazardous materials will be high, although presumably the level of hazard will have been reduced significantly, and in addition there will be a need for some degree of long-term or perpetual care. With these considerations in mind, it is apparent that proliferation of ultimate disposal sites or repositories is a situation to be avoided.

A discussion of siting considerations is given in Chapter VI.

Standards and Measures of Performance

In any system for the management of hazardous wastes, standards and criteria are necessary as points of reference for measuring performance. In the present context technical criteria will be required for site selection and for performance of the waste management system elements. Since hazardous wastes management is only one of several aspects of environmental and public health protection, the need for compatibility with other standards and criteria is apparent.

Priorities

As previously mentioned, the term "hazardous" is qualitatively and quantitatively ambiguous; several types of hazards and a wide variety of wastes can be so designated. Therefore, a priority-of-concern system should be applied to identify and quantify wastes with the greatest potential for harm to public health or the environment.

The issue of definition and designation of hazardous wastes has been mentioned. Definition and designation must be arrived at by evaluation of the intrinsic properties of the wastes in question. While this type of analysis achieves the appropriate designation of a waste as hazardous, it deliberately falls short of establishing priorities for action because the extrinsic elements in the system (those elements other than the simple existence of a hazardous material) are not considered.

The ultimate potential threat of a given waste depends upon the quantity of the waste involved, the extent to which present treatment technology and regulatory activities mitigate the threat, and the existing pathways to man or other critical organisms, i.e., the rates and routes of the intrinsic hazard to the point where damage can occur.

The concept of priority-of-concern ranking is further discussed and applied in Chapter III.

Information Needs

In order to physically institute a system for the management of hazardous wastes, a considerable information and technical data base is necessary. As pointed out earlier, points of origin of hazardous wastes are widely and unequally distributed throughout the United States. Similarly, wastes vary in makeup even if derived from presumably identical source types.

Facilities design will be highly dependent upon the characteristics of the region served by the processing and disposal sites. The information presently available on waste quantities, compositions, and distribution is sufficient to establish the national scope of the problem. To a more limited degree, regional judgments can be made. However, the specific facts necessary to support a firm design are not presently known and detailed regional surveys will be necessary.

Economic Issues

The economic issues of hazardous waste management relate principally to 1) cost, 2) methods of financing and distribution of the burden, 3) integration into the national economic framework, and 4) peculiarities arising from the properties of hazardous materials (e.g., perpetual stewardship requirements).

Management System Cost

The cost elements in a program of hazardous waste management include 1) capital facilities and real estate costs,

2) operating costs, 3) transportation costs, and 4) costs incurred in implementing and assuring that the system performs as intended. Compared to conventional waste management systems, hazardous waste systems will be more capital intensive.

Equitable Distribution of Burden

The method of distributing the costs of hazardous waste management will affect 1) the total net economic impact on society, 2) the equity of the distribution, and 3) trends in the future magnitude of the problem. If a system initially distributes costs to the waste producer, this may provide sufficient incentive for reduction in the quantities of hazardous wastes produced.

Maintenance of Competition

Since private industry is collectively the largest producer of hazardous wastes, the competitive economic framework must be recognized, as must the recent development and growth of service industries, particularly waste management organizations. A number of these firms are already operating in the hazardous waste disposal field in varying degrees.

Cost of Perpetual Care

When hazardous waste components cannot be recovered, destroyed, detoxified, or chemically or physically inerted, the problem of perpetual care is raised unless some means of ultimate disposal can be achieved.

Public Sector Financial Involvement

Public sector financial involvement will depend heavily upon the system adopted for implementation. It can range from simply bearing the costs of auditing to assure compliance with regulations up to assuming the responsibility for design, construction, and operation of the system with arrangements for distributing costs to the waste-generating entities.

In certain cases such as obsolete or unwanted munitions and waste generated in the course of nuclear weapons production, it is apparent that the public sector must bear the full burden. In other cases wherein the hazards are potentially much greater than society normally experiences and perpetual custodianship is necessary (as with radioactive wastes from the commercial nuclear power industry), the Federal Government has assumed responsibility for interim and ultimate disposal with full costs flowing back to the waste producer and ultimately to the electric power consumer.

Availability of Private Sector Capital

Although the costs of hazardous waste management can be returned to the wastes' originators, the question of availability of private sector capital for initial design and construction is one that should be considered. As previously noted, some private sector involvement is already apparent. Future involvement will depend largely upon the apparent incentive. The latter will in turn be conditioned by the manner in which a waste management program is implemented.

Resource Recovery Potential

The possible recovery of valuable materials in the course of hazardous waste management from both the hazardous constituents of the waste streams and the nonhazardous bulk materials is of economic interest. For instance, the economic viability of recovery of waste oils and solvents possibly contaminated with hazardous heavy metals is readily apparent.

Implementation and Administrative Issues

Considerations other than those of physical facilities and operations, namely institutional arrangements, must be considered in seeking improved management of hazardous wastes.

Implementation Options

Implementation of a system for hazardous waste management can be achieved by any of a wide spectrum of alternative approaches. At one end of this spectrum would be a Federally owned and operated system of processing plants and disposal sites with strict enforcement of requirements that wastes designated by the Federal Government as hazardous be treated and disposed of at these sites. The other end of the spectrum would see little more than the present voluntary practice. For example, the next incremental step in obtaining improved protection might be the development of recommended guidelines with the expectation of voluntary follow-through.

Within this spectrum of alternatives are numerous options with varying degrees of stringency in control. The objective is to select that option which achieves the national goal in the most cost effective manner.

Effectiveness of the System

The effectiveness of the system will be demonstrable and measurable by several parameters, including:

1. technical effectiveness in controlling hazardous wastes to assure environmental protection;
2. protection of the public interest through provision of appropriate public safeguards;
3. administrative workability including effective minimization of the cost of implementation to users and regulators;
4. ability to equitably allocate costs;
5. effectiveness in assuring efficient resources utilization;
6. enforcement provisions; and
7. achievement of desired goals within specified time limits.

Federal Cost and Employment

Paralleling the wide range of options in implementation is a great variation in the cost to the Federal Government and the level of Federal employment required. Federal involvement can take one of two forms: 1) operational and regulatory, or 2) regulatory only. Note that the first option includes the regulatory role, which is necessary to make the operational system viable. Depending upon the option chosen, the cost to the Federal Government can range from a relatively small investment sufficient to set standards and regulations and to provide some elements of monitoring and enforcement to the total costs of physical facilities, operational staff, and the parallel regulatory and enforcement program.

Since all implementation options which will achieve the national goal will ultimately involve similar capital facilities and operating costs, it follows that as Federal outlays diminish, private sector investment will increase in inverse proportion.

Legislative Requirements

Regardless of the implementation alternative selected, new legislation will be required. This can range from enactment of fairly simple laws establishing a regulatory system to the complex legislation necessary for a system incorporating tax incentives.

Compatibility with Environmental Protection Programs as a Whole

Systems for environmental and public health protection must be established and operated compatibly, so that efforts to eliminate one problem do not create different problems in another sector.

Private Sector Involvement

It is both desirable and inevitable that the private sector assume a major role in the management of hazardous wastes for several reasons:

1. the majority of such wastes are currently produced by the private sector;
2. the technology and know-how involved in handling and processing hazardous materials rests primarily in industry; and
3. private sector capital is already specifically involved in the management of hazardous wastes as an identifiable industry in its own right.

FRAMEWORK OF EVALUATION

In response to the mandate presented by Section 212 of the Resource Recovery Act of 1970, and in view of the problems indicated by the preceding discussion, the Environmental Protection Agency has conducted a comprehensive study and prepared the proposed Hazardous Waste Management Act of 1973 to meet national needs for improved management of hazardous wastes. In conducting this evaluation, resources of both the Environmental Protection Agency and the professional community have been utilized to the fullest extent.

The following report summarizes Battelle-Northwest's detailed findings and conclusions relating to the technical and administrative aspects of the problems involved and the means for achieving their solutions. Quite clearly, and as recognized by Section 212, a firm definition is needed at the outset as to what constitutes hazardous wastes, where they arise, what their properties are, and how they can be treated. Obtaining these essential definitions has constituted a major effort in the program.

Secondly, it has been necessary to evaluate processing and disposal techniques to determine 1) whether technical and engineering means are available for safe handling and disposition, 2) what types and sizes of facilities will

Back

potentially be required, and 3) what their capital and operating costs will be on a nationally averaged basis. In developing this information, estimates of waste quantities, types, and geographic distribution were developed, leading to the concept of a "model" waste treatment and disposal facility system capable of handling a complete spectrum of hazardous wastes. The service area is of reasonable size in order not to incur undue transportation costs on one hand or to lose the economies of scale on the other. The "model" concept serves the very useful purposes of establishing feasibility, highlighting practical considerations, and allowing an assessment of economic impact.

Thirdly, it was recognized that hazardous wastes by their very nature present a potential threat to public health and the environment over either short time periods prior to their destruction or over very long periods when detoxification cannot technically be achieved. Thus questions regarding the siting or processing and disposal systems were reviewed and, again, "model" siting concepts were developed and the feasibility of establishing such sites confirmed.

Finally, it was necessary to seek means of defining and implementing an improved system with due regard for the technical, economic, and administrative issues involved.

This report documents the development of the concept outlined above. Separate chapters are devoted to each of the principal elements involved in this program for the management of hazardous wastes.

CHAPTER CONTENTS

CHAPTER II

SUMMARY AND CONCLUSIONS

	Page No.
IDENTIFICATION AND DESIGNATION OF HAZARDOUS WASTES	17
WASTE MANAGEMENT METHODS AND COSTS	18
RADIOACTIVE WASTES	21
SITING CONSIDERATIONS	23
IMPLEMENTATION	24

CHAPTER II

SUMMARY AND CONCLUSIONS

In this chapter the principal conclusions developed during the course of this study are summarized. These are arranged into five key areas:

1. Identification and Designation of Hazardous Wastes
2. Waste Management Methods and Costs
3. Radioactive Wastes
4. Siting Considerations for Waste Treatment and Disposal
5. Implementation

More detailed discussions of findings and conclusions can be found at the beginning of each chapter.

IDENTIFICATION AND DESIGNATION OF HAZARDOUS WASTES

- Ideally, wastes should be designated as hazardous on the basis of the properties of the waste stream as an entity rather than according to the properties of individual constituents. When individual constituents only are considered, the potential for interactions between components of the waste and possible subsequent degradation products that may result after disposal are ignored. The hazardous properties of some wastes may be overlooked due to the constraints imposed by a necessarily limited list of known hazardous substances. The final disadvantage of this approach is the rather weak technical position which can result from oversimplification.

- The data necessary for proper evaluation of the true hazard potential of most wastes is unavailable. In order to generate the necessary data, a standard set of hazard potential testing evaluations such as those suggested in Chapter III of this report should be established and applied to waste streams.

- Implementation of such a hazard potential testing program could be accomplished through adoption of a broader waste discharge permit program covering discharges of all kinds, liquids, solids and gases.

Preceding page blank

- Due to the lack of sufficient waste stream property data, an interim technique is required for estimating the physical-chemical-toxicological characteristics of a waste. This can be done by assuming joint-additive properties of individual constituents within a waste. The approach then takes advantage of pure compound data for interim use in the waste stream decision model.

- Wastes should be designated as hazardous solely on the basis of intrinsic characteristics. Discharge of any waste designated as hazardous should be prohibited. Rather, such wastes should be treated onsite or transferred to a certified treatment or disposal facility.

- With further refinement, the hazardous waste decision model developed in this program may be employed as the tool for definition of hazardous wastes.

- The priority ranking system described in this report may be employed to develop a priority-of-concern system for fund allocation, resource utilization, and regulatory attention with regard to hazardous wastes management.

- A survey conducted during the course of this program led to an estimate of the current annual rate of non-radioactive hazardous waste generation in the United States as approximately 10,000,000 tons.

- Available information on the composition and quantities of potentially hazardous waste discharges in the United States is generally inadequate. A major effort should be expended to develop a comprehensive inventory of waste discharges on as detailed a level as possible.

- Existing and proposed discharge permit programs could provide continual update of the waste inventory.

- Areas of the country where hazardous wastes have been improperly buried or indiscriminantly dumped should be sought out, catalogued, and detoxified, if feasible. Since local knowledge is of paramount importance in this effort, State agencies concerned with public health and environmental protection would appear to be the most logical organizations to conduct this effort.

WASTE MANAGEMENT METHODS AND COSTS

Treatment capabilities required at hazardous waste processing facilities will depend on the types and volumes of hazardous wastes generated in the vicinity of the facility. Broad treatment capabilities may be required for a facility located in a heavily industrialized area whereas only limited treatment capability may be necessary for a facility located in a lightly industrialized area. For the purposes of this phase of the study, a model facility capable of processing a wide variety of hazardous wastes (excluding radioactive and DOD wastes) was considered. Conceptual design and cost estimates were prepared for a complete waste management system to process and dispose of the wastes. Findings and conclusions are summarized as follows:

- Hazardous wastes are generally complex mixtures of several chemical species. Therefore, more than one treatment method is frequently required to convert the waste to a form suitable for disposal and/or reuse. Treatment for non-hazardous constituents within a hazardous waste may dictate the type of process used and may entail the most significant operational costs (e.g., acid neutralization).

- Major site types required for a national hazardous waste management system include a processing site to treat the wastes and a disposal site for burial of the hazardous residue generated at the processing site. Processing sites may be located near the sources of the wastes while the disposal sites may be located in arid regions of the Western United States to avoid potentially high costs of non-leachable containment.

- Regulations should be considered for specifying incineration or some other form of destructive disposal for all wastes defined as hazardous solely on the basis of explosivity or flammability.

- Thirty-nine potential physical, chemical, and biological treatment processes were reviewed for possible use in the model processing facility. Because of the toxic nature of the hazardous wastes, expected variable chemical character, and throughput, biological processes were rejected and the following physical/chemical processes were selected to provide broad treatment capabilities in the model processing facility:

    1. Neutralization (of acids and bases)

    2. Oxidation (of cyanides and other reductants)

    3. Reduction (of chromium-6 and other oxidants)

    4. Precipitation (removal of heavy metals)

5. Flocculation, sedimentation and filtration (separation of solids from liquids)

6. Carbon sorption (removal of organics)

7. Incineration (of combustible wastes)

8. Ammonia stripping (removal of ammonia)

9. Evaporation (concentration of waste brines)

- Using the best technology that has been demonstrated on an engineering or plant scale, conceptual designs were prepared for a medium-sized model processing facility capable of treating 122,000 gallons per day of wastewater and 74 tons per day of combustible waste.

- Preliminary capital and operating cost estimates for the medium size processing facility are $24,000,000 and and $39,000 per day, respectively. Wastewater processing costs were estimated to average 20 cents per gallon and incineration costs to average $175 per ton.

- Preliminary capital and operating cost estimates were prepared for a small facility capable of processing 25,000 gallons per day of wastewater and 15 tons per day of combustible waste. A capital cost of $7,300,000 and an operating cost of $14,000 per day was estimated. Wastewater processing cost was estimated at 35 cents per gallon and incineration cost at $400 per ton.

- Preliminary capital and operating cost estimates were also prepared for a large facility capable of processing 1,000,000 gallons per day of wastewater and 600 tons per day of combustible waste. A capital cost of $86,000,000 and an operating cost of $186,000 per day were estimated. Wastewater processing cost is 12 cents per gallon and the incineration cost is $100 per ton.

- On an overall national basis it is expected that plant sizes and geographic distribution will evolve as a consequence of market forces. A reasonable prediction, however, is that the national needs can be met in the near term by five large-sized and fifteen medium-sized processing plants. On this basis, the overall national costs will be about $800 million in capital investment and about $580 million per year for operating costs.

- Disposal methods for liquid and solid wastes generated by the processing facility include ocean dumping and deep well injection for liquid brine wastes which do not contain hazardous constituents and landfilling for solid wastes. Landfills consist of two types: (1) secured landfills especially designated for the disposal of sludges containing significant concentrations of hazardous substances (e.g., arsenic), and (2) conventional landfills for burial of solid wastes which do not contain significant concentrations of hazardous substances. Perpetual surveillance will be maintained over the secured landfill as in a radioactive waste burial site.

- It is anticipated that private processors will design treatment facilities to process both hazardous and nonhazardous (polluting) wastes to benefit from economies of scale. The volume of nonhazardous wastes may exceed the volume of hazardous wastes by considerable margins in many areas.

- Resource recovery is expected to be practiced in the non-hazardous waste processing area, particularly for waste solvent recovery. Heavy metal and oil recovery may also be economically attractive.

- Further studies on burial of waste sludges in landfills are recommended to determine the long term stability and leachability of the sludges under a variety of conditions, including the admixture of fixation agents.

- A paucity of data exists on the concentration of specific hazardous substances (e.g., pesticides) in the gaseous wastes from different incineration systems under variable operating conditions.

RADIOACTIVE WASTES

Radioactive wastes present a special case in that (1) their associated hazards are several orders of magnitude higher than those of any other materials, (2) they are already regulated to a high degree, (3) the rate of generation during the foreseeable future is expected to increase dramatically, and (4) the traditional Federal Government role in their management is being expanded. Key findings are as follows:

- Techniques exist for safe interim storage of radioactive wastes for time periods in the order of 100 years using high-integrity man-made structures.

However, no fully evaluated and technically acceptable concept for ultimate disposal of radioactive wastes exists today.

- By the year 1980, the total volumes of high- and low-level radioactive wastes after processing to achieve volume reduction are expected to exceed 1 x 10^3 and 7 x 10^5 cubic feet per year, respectively.
- The nuclear electric power industry, the major source of such wastes, is expected to increase by a factor of eight between 1980 and the year 2000.
- The long-term hazards associated with radioactive wastes are not necessarily proportional to whether they are high or low level; many low-level wastes have significantly higher long-term hazards than many high-level wastes. Waste management practices should strongly reflect consideration of these long-term hazards.
- Planning is currently underway by the AEC for an interim retrievable surface storage system for high-level wastes at a Federal repository. This facility will be designed to accommodate wastes generated by the nuclear power economy through the year 2000. The expected service life of this facility will be a minimum of 100 years, with the expectation that an ultimate disposal concept will be developed during that period.
- So-called low-level radioactive wastes, e.g., those not requiring special management techniques as a consequence of their heat generation, are currently disposed of by shallow burial at six State-licensed sites under regulations promulgated by the Federal Government. Considering the expected growth of the nuclear power economy, proliferation of such sites can be expected if the present system of disposal is continued.
- These private State-licensed disposal sites are designed and operated with little or no consideration of future retrieval for ultimate disposal. In contrast, USAEC contractor-operated sites presently require that disposal practices provide for future retrieval within a minimum of twenty years.
- Planning for improved management of low-level wastes should be initiated. This document describes an initial conceptual design for a retrievable storage system for low-level wastes. It would be desirable to have implementation of plans for high-integrity storage of low-

level wastes in effect by the early 1980's, or before the effects of the expected rapid growth period in nuclear electrical power are felt.

- Two concepts are described for retrievable storage repositories to be operable by about the early 1980's for radioactive wastes: one for high-level waste which requires significant cooling provisions and one for low-level wastes. The high-level waste repository concept, which was derived from AEC studies, accepts only previously solidified and encapsulated wastes and stores them in modular water basins. The low-level waste repository accepts untreated liquid or solid wastes and encapsulated pretreated solid wastes, concentrates and converts the liquid wastes to solids, incinerates all combustible wastes to ashes, cans the final solid waste forms, and stores them in special modular warehouses.

- The capital costs for the conceptual high-level radioactive waste repository with capacity for the wastes which will be accumulated through 1980 were estimated at $37,000,000 and the operating costs at $3,300,000 per year. Transportation operating costs for 1980 were estimated at $2,600,000 per year. All costs are in 1973 dollars.

- The capital costs for the conceptual low-level radioactive waste repository with capacity for wastes which will be accumulated through 1980 were estimated at $44,000,000 and operating costs at $6,900,000 per year. Transportation operating costs for 1980 were estimated to be $31,000,000 per year. All costs are in 1973 dollars.

SITING CONSIDERATIONS

- In selecting sites for the processing and disposal of hazardous wastes, consideration must be given to four principal categories of information:

  1. earth sciences;

  2. transportation;

  3. ecology; and

  4. human environment and resources utilization.

- In general, hazardous waste processing (as distinct from disposal) facilities, their operations, and level of hazard to the surrounding population are fairly similar to present-day experience in the chemical industry. Thus, siting of waste processing facilities can be achieved with considerable flexibility provided appropriate engineered safeguards are applied.

- Processing site selection will be determined largely by the quantities and geographic distribution of waste sources within the region to be served, i.e., the "market", and the availability of suitable disposal sites for nonhazardous but often bulky residual materials.

- There are two notable exceptions to this: (1) the processing of radioactive wastes to a solidified form (in which case the siting criteria for nuclear facilities must be applied), and (2) the processing of obsolete unconventional chemical munitions. In both these cases, much greater emphasis should be given to the demographic and environmental siting of these facilities.

- In the case of final disposal sites for hazardous wastes, i.e., when detoxification or destruction cannot be practically achieved, the hazard inventory will be markedly higher and can well exist in perpetuity. In these instances, careful attention should be given to the aforementioned criteria areas.

- At the present time site standards for the land disposal of hazardous wastes have not been established. It would appear that such standards should be developed and promulgated with the intention that they be used as guidance in site selection and qualification as well as for licensing.

IMPLEMENTATION

- In considering means of implementing a system for the management of hazardous wastes, it has become apparent that a wide range of options is available, particularly in the institutional arrangements which can be employed.

- Of the twelve institutional arrangements analyzed in this report (ranging from a totally Federally owned and operated system to little more control than is presently exercised), it appears that the most effective alternate is a combination of Federal responsibilities and standards for hazardous waste management with the operation of privately owned waste processing, storage, and disposal facilities under a license issued and controlled by the Federal Government. State participation in implementation and enforcement appears desirable.

- To be effective, any implementation plan, regardless of how constituted, will require the establishment of standards and the regulatory and enforcement machinery necessary to obtain adherence.
- It is expected that the implementation of a regulatory program will result in modest restructuring of business practices and will in effect create a market for an already emerging hazardous waste management service industry. The rate of this emergence will be highly sensitive to the nature of the standards and regulations, and even more so to their degree of enforcement.
- State and lower jurisdictional level legislative activities in hazardous waste management are, for the most part, minimal. Of sixteen States surveyed, only Oregon and California have enacted comprehensive hazardous wastes disposal leglislation.

CHAPTER CONTENTS

CHAPTER III

DEFINITION AND IDENTIFICATION OF HAZARDOUS WASTES

	Page No.
BRIEF	29
DEFINITION OF HAZARDOUS WASTES	30
Hazards of Concern	31
Flammability	31
Reactivity	31
Toxicity	32
Radioactivity	33
Bioconcentration	34
Irritation	35
Genetic Change Potential	35
EXISTING DEFINITIONS OF HAZARDOUS MATERIALS	35
The Pure Compound Approach	36
The Hazardous Waste Decision Model	42
Radioactivity	44
Bioconcentration	44
Flammability	45
Reactivity	46
Oral Toxicity	47
Inhalation Toxicity	48
Dermal Penetration	50
Dermal Irritation	50
Aquatic Toxicity	51
Phytotoxicity	51
Genetic Effects	52
Application of Model to Waste Streams	53
INVENTORY OF HAZARDOUS WASTES	54
DEPARTMENT OF DEFENSE WASTES	64

Preceding page blank

CHAPTER CONTENTS (Continued)

Page No.

Biological, Chemical, and Explosive Wastes 66

- *Biological Agents* 66
- *Chemical Agents* 67
- *Explosive/Ordnance* 71

PRIORITY OF CONCERN 73

CHAPTER III

DEFINITION AND IDENTIFICATION OF HAZARDOUS WASTES

BRIEF

Many wastes generated by man's activities are hazardous in nature and consequently require special management techniques. The hazards posed by these wastes result both from intrinsic properties and from extrinsic circumstances of exposure. Various classification systems have been devised for designating materials or wastes which pose hazards greater than those which can be handled by normal management practices. Since these classification systems were designed for specific purposes, their characteristics vary widely, and each places emphasis on particular properties of materials in light of the needs for which the respective schemes were devised. No single system has been formulated to cover all of the concerns related to disposal of hazardous wastes.

To remedy this situation preliminary classification methodologies have been suggested based on evaluation of the hazardous properties of the pure constituents of the wastes. Such an approach, however, is unrealistic since it completely ignores the potential for interaction among various components in a waste and thus potentially misstates the waste's actual hazard. Data pertaining to the physical-chemical-toxicological properties of pure chemicals can be helpful, but should not be used as the sole basis for assessing the nature and hazards of a complex waste.

To meet the need for a workable designation tool, Battelle formulated a hazardous waste decision model which evaluates waste stream parameters and compares them to established threshold levels. Thresholds for a number of parameters which can cause damage to man or the environment have been delineated and wastes which exceed any of these threshold levels are designated hazardous. Each threshold level is handled as an individual module to retain maximum flexibility in the model. Changes in regulatory position or new information bearing on the true nature of various hazards can be accommodated quickly through modification of the pertinent threshold in the decision model.

The decision model is viewed as a comprehensive regulatory device. The body of wastes found to qualify as hazardous define the area of control for hazardous wastes legislation. Wastes so qualifying are restricted from normal disposal operations. Rather, they must be treated at the point of generation so as to no longer fall in the category of hazardous, or they must be transferred to a certified hazardous waste processing and disposal facility.

A formulation was also developed by Battelle to rank waste streams on an ordinal scale representative of the priority of concern they deserve. The formulation addresses itself to volume of production and mobility as well as the intrinsic hazard inherent in the waste.

During the progress of the study reported herein, data were collected on various waste streams qualifying as hazardous under preliminary pure constituent criteria. This information was found to be inadequate for proper management of hazardous wastes. The required data on waste stream volumes, composition, and location are not available. There is an urgent need for development of a complete inventory of wastes being discharged into the biosphere.

A waste volume survey conducted during the course of this program let to an estimate of the current annual hazardous wastes generation in the United States as approximately 10,000,000 tons. Fifteen medium sized hazardous wastes processing and disposal facilities, each with a 122,000 gallon per day capacity, and five large plants with 1,000,000 gallons per day capacities would be required to handle this quantity of waste.

DEFINITION OF HAZARDOUS WASTES

Hazardous wastes in general have been defined as:

> *...those materials or combinations of materials which require special management techniques because of their acute and/or chronic effects on the health or welfare of the public (or those individuals who handle them) when they are disposed of by waste management processes...*

Such a definition is too broad to govern the selection and designation of specific hazardous wastes. It leaves to individual judgment such decisions as: what levels of acute or chronic effects require "special" management techniques? Indeed, what are "special" management techniques? Consistent, objective decision making requires a quantitative formulation. In order to design such a formulation, it is first necessary to define hazards of concern.

Hazards of Concern

The term "hazardous" has two distinct connotations, one of which relates to the intrinsic properties of the waste itself, or the amount of damage that it can render to man or the environment. The second connotation relates to extrinsic factors: the degree of exposure of man or the environment to the hazard, including quantity, behavior, delivery mechanism, and circumstances surrounding exposure. In the former case, the information required for assessing the degree of hazard is specific to the waste; in the latter the information depends upon individual disposal situations. Clearly, a general decision model cannot take into account the multitude of variables involved with extrinsic factors. Therefore it is the intrinsic factors, or hazards of concern, upon which designation of hazardous wastes must hinge. Hazardous wastes are generally flammable, reactive, toxic, radioactive, irritating, and/or genetically active to an unacceptable degree. For numerous reasons these intrinsic properties are cause for concern.

Flammability

Highly flammable wastes can pose both acute handling and latent disposal hazards. Handling problems involve safety hazards to personnel at the site of origin, during transport, and at the disposal site. An example of a latent disposal hazard is the potential damage caused by unintentional or spontaneous combustion of flammable residues at a disposal site. Fear of such consequences has lead to a ban on the landfilling of flammable liquids in many areas.

Both acute and latent hazards relate to injury, destruction of property, and/or rapid depletion of resources. A 9,000 gallon tank truck and a 30,000 gallon tank car of flammable liquid are likely to be associated with kill radii of 115 and 230 feet respectively if ignited during handling or transport operations.[6] Secondary effects beyond the initial disaster area may include ignition of nearby inflammables and detonation of heat sensitive substances in the vicinity. Hazards related to disposal sites may exceed those of transportation and handling if sufficient waste volumes are involved. Flammable wastes may include contaminated solvents, oils, pesticides and plasticizers; complex organic sludges; or off-specification chemicals.

Reactivity

Highly reactive wastes may be detonated by several mechanisms:

thermal shock, mechanical shock, electrostatic charge, or contact with incompatible materials. Like flammable wastes, highly reactive ones may threaten life and property in an acute and a latent sense in that detonation may occur before or after "disposal". In the first case, handling, shipment, or disposal operations can initiate violent reactions, resulting in an explosion. In the second case, reactive materials may be buried in a landfill and, like a time-bomb, await the appropriate conditions for detonation.

Typically, the kill radius for explosive wastes will be less than that for comparable volumes of flammable liquids. Prior experience with transportation-related explosions indicates a casualty radius of 100-200 feet.[6] Detonation of a single waste may be followed by secondary explosions or fire. The magnitude of the hazard existing after completion of disposal activities may exceed the handling hazard if sufficient waste inventory is accumulated.

Reactive wastes include explosive manufacturing wastes, contaminated industrial gases, and old ordinance.

Toxicity

Toxicity is the ability of a waste to produce injury upon contact with a susceptible site in or on the body of a living organism. Toxicity hazard is the risk that injury will be caused by the manner in which the waste is handled.[7] Wastes may be acutely or chronically hazardous to plants or animals via a number of routes of administration. Phytotoxic wastes can damage plants when present in the soil, atmosphere, or irrigation water. Phytotoxicity is the result of a reduction of chlorophyl production capability, overall growth retardation, or some specific chemical interference mechanism. A typical example of a phytotoxic substance is boron.

Wastes which are acutely toxic to mammals may be active when inhaled, ingested, and/or contacted with the skin. Acute effects are generally evidenced within hours of inhalation or after a single dermal or oral dose. Data pertinent to a single route of administration may not be applicable to alternate routes. Hence, beryllium dust is toxic at very low levels when present in the air, but beryllium dissolved in water poses no ingestive threat at low levels.

Wastes may be chronically toxic to mammals if they contain materials which 1) are bioaccumulated or concentrated in the food chain, or 2) cause irreversible damage that builds gradually to a final, unacceptable level. Classic examples of chronic toxicants are the heavy metals and halogenated aromatic compounds.

Wastes can also be highly toxic to aquatic organisms. Much data exists on the effects of various materials on fish and fish food organisms. (Toxicity in these cases may result from transfer of toxic materials across the gill membrane surface and hence toxicity information may not always be deduced from existing information on mammalian toxicity.)

Because of the various routes of exposure which may ultimately lead to hazardous effects, toxicity must be viewed as a function of the transport media, the physical characteristics of the waste, and type of disposal practices involved.

Although water is perhaps the most pervasive vector, atmospheric emissions may well travel faster and spread farther. Direct contact is the most easily controlled route of exposure.

Toxic wastes can be derived from practically any industry. Toxicity may be the result of pure constituents within the stream, the total effects of several similar waste stream components, or the combined action of two individually nontoxic materials (*binary synergism*).

Radioactivity

Ionizing radiation results from an instability of the nucleus of an atom. The drive toward stability causes a radioactive release which may be manifested in one of many forms. The four major types of radiation are listed below:[8]

1. Alpha particles consist of two protons and two neutrons and are the largest and heaviest of the emissions. Interaction with orbital electrons slows alpha particles considerably and thus they do not travel more than three inches when emitted in air. Consequently, they are incapable of penetrating the dead outer layer of human skin. Ingestion, inhalation, or adsorption of alpha emitters can be extremely hazardous, however, because of their potential ability to damage internal organs unprotected by epidermal layers. Elements with an atomic number of 84 or greater are typical alpha emitters.

2. Beta particles are electrons emitted at high speeds. Their small size and great velocity allow beta particles to travel as far as 10-100 feet in air, and yet few can penetrate human skin by as much as half an inch. Excessive external doses can produce skin burns while internal doses can be highly hazardous even at very low levels. Effects include debilitation of reproductive capability and injury to specific organs.

3. Gamma radiation is electromagnetic energy rather than matter. In contrast to alpha radiation, gamma radiation poses an extreme external as well as internal exposure hazard because of its ability to travel great distances and deeply penetrate human tissue. Gamma rays may not be as hazardous when present internally because of their ability to exit the body without colliding with electrons and causing damage. Many radioisotopes of common elements are gamma emitters.

4. Neutrons separated from the nucleus and traveling at very high speeds constitute a fourth form of radiation. While human exposure is rare, it is extremely dangerous due to tissue penetrating capabilities exceeding several feet.

Several major health hazards may result from exposure to radiation: 1) large acute external doses may result in burns or damage to internal organs; 2) large acute internal doses may result in damage to internal organs; 3) low level chronic internal doses may accumulate in the body until toxic action results; 4) radiation can interfere with the normal functioning of the nucleus of human cells leading to malignancy; and 5) irradiation of reproductive organs can lead to sterility or possibly harmful mutations.

Wastes containing radioactive materials may cause any and all of the above effects. Acute exposure could result from improper handling by employees or improper disposal to nonsecured locations. Chronic exposure could potentially result from leaching of landfills, volatilization of radioactive materials, or casual proximity to unmarked repositories.

Bioconcentration

The term bioconcentration is used to describe the hazard posed by materials which can be concentrated in a single organism or magnified by successive levels in the food chain until they reach toxic levels. The hazard is one of chronic exposure and generally occurs when the contaminant is present in the environment at low levels.

Wastes may possess this characteristic as a result of the presence of bioconcentrative constituents such as cadmium, lead, mercury, polychlorinated biphenyls, or carbon tetrachloride. Improper disposal of these wastes can lead to release of low levels of bioconcentrative materials to the environment. Organisms may then pick up and concentrate these materials until concentration reaches a sufficient level to cause death. Concentration to the threshold toxic level often occurs in higher life forms such as fish, birds, and mammals, including man.

Irritation

Some wastes, namely those containing allergens capable of sensitizing skin, agents which cause contact dermatitis, or substances which are corrosive to living tissues, can cause severe discomfort if contacted. Examples of these wastes are concentrated acids and alkalis, waste warfare agents, and waste substances with allergenic properties. Such wastes pose a hazard when discharged to waterways or uncontrolled landfills where accidental exposure cannot be prevented.

Genetic Change Potential

Wastes may contain materials with carcinogenic, mutagenic, or teratogenic properties, evidenced as malfunctions of the genetic process either in mitosis or meiosis. When chemically induced such effects may be the result of chemical modification of DNA nucleotides in the target species. Exposure routes are usually direct and continuous.

Dye plant wastes and petroleum sludges can contain genetically active materials. The California Hazardous Wastes Working Group[9] notes that

> *Most proofs of carcinogenesis in humans are limited to occupational exposures but there is probably a general population exposure of unknown magnitude. Various reports substantiate this assumption in one way or another and give emphasis to the urgent need for comprehensive chemical, experimental, and epidemiologic studies to determine actual hazards.*

EXISTING DEFINITIONS OF HAZARDOUS MATERIALS

It has been noted in prior studies that while numerous writers have struggled with the term "hazardous material", no single, satisfactory definition has evolved. In fact, even the term "toxic" has been the subject of continuing recent controversy.[10] Agreement can be reached at the extremes. All parties agree that high explosives, radioactive substances, and deadly poisons are hazardous, while most foodstuffs and natural products are not. The debate focuses on the gray area between these extremes.

Because hazard connotes previously discussed extrinsic factors as well as inherent hazard, the ambiguous area between the extremes has been divided in different ways by various interest groups, each striving to analyze hazard within the context of a narrow range of situations. Consequently, each has derived a unique set of criteria for assessing hazard. Most schemes developed to date, however, have recognized that any material may be hazardous in a given context. Potter has stated,

> *It is absolutely indisputable that any given substance in the proper time or proper place or proper circumstances can be hazardous.*

To make a point: water, if deep enough, is hazardous to someone who cannot swim.

Given this context, most work in the past has focused on categorizing or grouping materials in a hierarchical relation and labeling each group, such as Class A poisons and Class B poisons. By 1970 there were more than 30 major classification systems being employed to characterize hazardous substances during transportation operations. Table 1 illustrates the various types of criteria which can be applied for these classification schemes.

Past classification schemes, however, have not addressed themselves to wastes. Rather, they have dealt with pure substances and commercial products. Systems for evaluating fire and explosion hazard have generally been based on graded levels related to initiation of combustion or explosive action.[13,14] Systems emphasizing toxic or irritating materials typically select dose thresholds at or below that at which given reactions occur.[15-18] Radioactivity and carcinogenicity are usually specified as either present or not present.

Since hazardous wastes may pose any or all of these problems, no single existing system is adequate for classifying all wastes; a hybrid system is required for use in defining hazardous waste types Development of such a system was attempted by TRW Systems Group, Inc.[19] and can be identified as the *pure compound approach.*

The Pure Compound Approach

The pure compound approach is predicated on the assumption that the hazardous properties of a waste will be those of the most hazardous pure compound within the waste. Using threshold levels established for the various hazardous properties, wastes containing compounds with values less than or equal to these thresholds are classified as hazardous. This approach takes advantage of the available hazard data on pure chemicals and avoids speculation on potential compound interactions within a waste stream.

The criteria for selection of hazardous compounds were chosen to emphasize two major concerns: the existence of a hazard, and the inability to sufficiently reduce that hazard on-site. TRW employed four criteria during their selection process.[19]

TABLE 1

POSSIBLE CLASSIFICATION SYSTEM CRITERIA FOR CATEGORIZATION OF HAZARDOUS MATERIALS[12]

1. Identification of Hazardous Material

    A. Name
    B. Chemical class
    C. Physical and chemical properties
    D. Toxicology

2. Specification of Nature of Hazard

    A. Overall effect
    B. Attack by hazardous material
    C. Possible accident
    D. Chemical and physical effects
    E. Hazard class

3. Specification of Degree of Hazard

4. Specification of Mode of Transport

    A. Truck
    B. Rail
    C. Air
    D. Water
    E. Pipe
    F. Combinations of modes

5. Specification of Handling Activity Required or Expected

    A. Transport
    B. Store
    C. Use en route
    D. Combination

6. Specification of Expected Environmental Stresses in Handling

    A. Thermal
    B. Mechanical shock or vibration
    C. Abrasion
    D. Compression
    E. Impact

TABLE 1 (Continued)

   - F. Puncture
   - G. Pressure
   - H. Moisture
   - I. Combinations of stresses

7. Specification of Corrective Actions to be Taken in Case of Accident

8. Specification of Exemptions and Exceptions to Above

9. Compatibility with Other Substances

10. Detectability

11. Availability of Techniques for Neutralization of a Spill

1. Material has an estimated 24 hr TLV $\leq$ 1 ppm.
2. Material is spontaneously combustible in air.
3. Material is highly explosive, rated $\leq$ 5 inches on the Picatinny Arsenal scale using a $\overline{2}$ Kg drop weight. (The 5 inch level was selected since it differentiates between primary and secondary explosive materials.)
4. Material requires costly or highly sophisticated technology for disposal.

Candidate materials for consideration as hazardous were selected by Booz-Allen in a recent study on the basis of their intrinsic properties and production quantities.[10] TRW then reviewed these candidates with respect to the aforementioned criteria. Table 2 lists the compounds tentatively designated as hazardous under this selection procedure. Any waste stream containing one of these constituents at a significant level was subsequently classified as hazardous. Beryllium and asbestos were deleted from the list though considered as aerosol hazards. Subsequent findings indicate that both should have been retained on the list.

The pure compound approach has one major advantage in that pure compound data is more readily available than waste stream data. This is a source of weakness also, however, since this system fails to recognize that the interactions of various waste stream constituents can drastically alter the hazardous nature of a waste. The classic example of interactive alteration is synergism, the working together of two or more materials to create a combined toxicity greater than the sum of their individual effects. For instance, chlorinated aromatics become far more toxic in the presence of various solvents. Heavy metals like cadmium and selenium can be synergistic to each other. Other interactions which cause alterations include antagonism, (the functional opposite of synergism in which the combined toxicity is less than the sum of the parts) complex formation, and chemical reaction potential.

Another significant weakness in the original selection criteria is the failure to consider the full range of hazard types. While explosiveness, flammability, and inhalation toxicity are important considerations, they do not reflect the entire range of significant hazards. Of particular concern are dangers related to oral ingestion, dermal contact, aquatic toxicity, phytotoxicity, and genetic change potential. These properties cannot be deduced from inhalation data. In many instances

TABLE 2

NONRADIOACTIVE HAZARDOUS COMPOUNDS EMPLOYED FOR PURE COMPOUND SELECTION PROCEDURE

MISCELLANEOUS INORGANICS

AMMONIUM CHROMATE
AMMONIUM DICHROMATE
ANTIMONY PENTAFLUORIDE
ANTIMONY TRIFLUORIDE
ARSENIC TRICHLORIDE
ARSENIC TRIOXIDE
CADMIUM (ALLOYS)
CADMIUM CHLORIDE
CADMIUM CYANIDE
CADMIUM NITRATE
CADMIUM OXIDE
CADMIUM PHOSPHATE
CADMIUM POTASSIUM CYANIDE
CADMIUM (POWDERED)
CADMIUM SULFATE
CALCIUM ARSENATE
CALCIUM ARSENITE
CALCIUM CYANIDES
CHROMIC ACID
COPPER ARSENATE
COPPER CYANIDES
CYANIDE (ION)
DECABORANE
DIBORANE
HEXABORANE
HYDRAZINE
HYDRAZINE AZIDE
LEAD ARSENATE
LEAD ARSENITE
LEAD AZIDE
LEAD CYANIDE
MAGNESIUM ARSENITE
MANGANESE ARSENATE
MERCURIC CHLORIDE
MERCURIC CYANIDE
MERCURIC DIAMMONIUM CHLORIDE
MERCURIC NITRATE
MERCURIC SULFATE
MERCURY
NICKEL CARBONYL
NICKEL CYANIDE
PENTABORANE-9
PENTABORANE-11
PERCHLORIC ACID (TO 72%)
PHOSGENE (CARBONYL CHLORIDE)
POTASSIUM ARSENITE
POTASSIUM CHROMATE
POTASSIUM CYANIDE
POTASSIUM DICHROMATE
SELENIUM
SILVER AZIDE
SILVER CYANIDE
SODIUM ARSENATE
SODIUM ARSENITE
SODIUM BICHROMATE
SODIUM CHROMATE
SODIUM CYANIDE
SODIUM MONOFLUOROACETATE
TETRABORANE
THALLIUM COMPOUNDS
ZINC ARSENATE
ZINC ARSENITE
ZINC CYANIDE

HALOGENS & INTERHALOGENS

BROMINE PENTAFLUORIDE
CHLORINE
CHLORINE PENTAFLUORIDE
CHLORINE TRIFLUORIDE
FLUORINE
PERCHLORYL FLUORIDE

MISCELLANEOUS ORGANICS

ACROLEIN
ALKYL LEADS
CARCINOGENS (IN GENERAL)
CHLOROACETOPHENONE

CHLOROPICRIN
COPPER ACETYLIDE
COPPER CHLOROTETRAZOLE
CYANURIC TRIAZIDE
DIAZODINITROPHENOL (DDNP)
DIMETHYL SULFATE
DINITROBENZENE
DINITRO CRESOLS
DINITROPHENOL
DINITROTOLUENE
DIPENTAERYTHRITOL HEXANITRATE (DPEHN)
GB (PROPOXY(2)-METHYLPHOSPHORYL FLUORIDE)
GELATINIZED NITROCELLULOSE (PNC)
GLYCOL DINITRATE
GOLD FULMINATE
LEAD 2,4-DINITRORESORCINATE (LDNR)
LEAD STYPHNATE
LEWISITE (2-CHLOROETHENYL DICHLOROARSINE)
MANNITOL HEXANITRATE
NITROANILINE
NITROCELLULOSE
NITROGEN MUSTARDS (2,2',2" TRICHLOROTRIETHYLAMINE)
NITROGLYCERIN
ORGANIC MERCURY COMPOUND
PENTACHLOROPHENOL
PICRIC ACID
POTASSIUM DINITROBENZFUROXAN (KDNBF)
SILVER ACETYLIDE
SILVER TETRAZENE
TEAR GAS (CN) (CHLOROACETOPHENONE)
TEAR GAS (CS) (2-CHLOROBENZYLIDENE MALONONITRILE)
TETRAZENE
VX (ETHOXY-METHYL PHOSPHORYL N,N DIPROPOXY-(2-2), THIOCHOLINE)

PESTICIDES & ORGANIC HALOGEN COMPOUNDS

ALDRIN
CHLORINATED AROMATICS
CHLORDANE
COPPER ACETOARSENITE
2,4-D (2,4-DICHLOROPHENOXYACETIC ACID)
DDD
DDT
DEMETON
DIELDRIN
ENDRIN
ETHYLENE BROMIDE
FLUORIDES (ORGANIC)
GUTHION
HEPTACHLOR
LINDANE
METHYL BROMIDE
METHYL CHLORIDE
METHYL PARATHION
PARATHION
POLYCHLORINATED BIPHENYLS (PCB)

materials are highly toxic to plants or aquatic life but only moderately or slightly toxic to man. Materials such as beryllium are extremely dangerous when inhaled but relatively harmless when dissolved in drinking water. Clearly, thresholds must be established for the full range of hazards rather than relying on a single toxicity measurement for extrapolation to other sectors in the biosphere and alternate routes of exposure.

Finally, the pure compound approach was designed to assess treatability. This is a judgmental decision and clouds the objectivity of the screening criteria. Regulations controlling designation of hazardous wastes will be more technically defensible and more practical for use in the future if this subjective judgment can be eliminated. In order to accomplish this, a hazardous waste decision model has been formulated.

The Hazardous Waste Decision Model

The hazardous waste decision model is designed to reorient the pure compound approach to a more objective methodology. The use of comparative threshold levels is retained, but the basic criteria for judgment are expanded to cover a full range of hazard types. Constituent interactions are taken into account as fully as possible by use of available waste stream data.

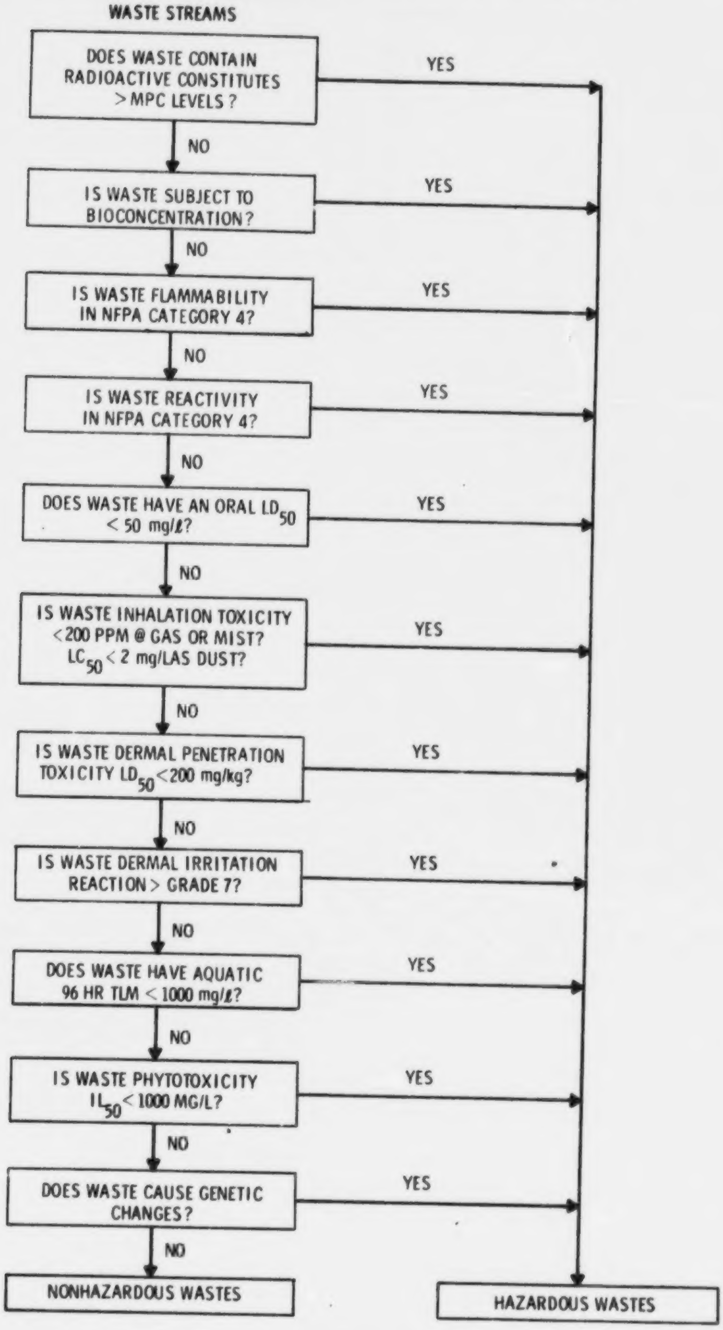
The selection process is analogous to a screening operation. Candidate wastes are examined in a manner illustrated by the logic diagram, Figure 1. Affirmative response to any of the criteria, or screens, automatically qualifies the waste as hazardous. All wastes are considered candidates for the screening procedure, regardless of production quantities. While low volume streams will be unimportant in designing individual treatment facilities, they must be classified and regulated as hazardous if their intrinsic properties so warrant.

A subjective treatability assessment is avoided by evaluating waste streams as they exit the plant's boundaries. Hence, if on-site processing adequately reduces waste stream properties below the designated thresholds, the resulting discharges will not be classified as hazardous. On the other hand, sludges or concentrates resulting from on-site treatment may well be sufficiently dangerous to qualify as hazardous. These by-product streams would then be so designated.

This concept allows for continual updating of designations and regulations as new production techniques and treatment systems modify existing wastes and as new wastes are produced. The rationale for the thresholds selected for use in the hazardous waste decision model follow.

FIGURE 1

GRAPHIC REPRESENTATION OF THE HAZARDOUS WASTE DECISION MODEL


WASTE STREAMS
DOES WASTE CONTAIN RADIOACTIVE CONSTITUTES > MPC LEVELS ?
YES
NO
IS WASTE SUBJECT TO BIOCONCENTRATION?
YES
NO
IS WASTE FLAMMABILITY IN NFPA CATEGORY 4?
YES
NO
IS WASTE REACTIVITY IN NFPA CATEGORY 4?
YES
NO
DOES WASTE HAVE AN ORAL LD50 < 50 mg/ℓ?
YES
NO
IS WASTE INHALATION TOXICITY < 200 PPM @ GAS OR MIST? LC50 < 2 mg/LAS DUST?
YES
NO
IS WASTE DERMAL PENETRATION TOXICITY LD50 < 200 mg/kg?
YES
NO
IS WASTE DERMAL IRRITATION REACTION > GRADE 7?
YES
NO
DOES WASTE HAVE AQUATIC 96 HR TLM < 1000 mg/ℓ?
YES
NO
IS WASTE PHYTOTOXICITY IL50 < 1000 MG/L?
YES
NO
DOES WASTE CAUSE GENETIC CHANGES?
YES
NO
NONHAZARDOUS WASTES
HAZARDOUS WASTES

Radioactivity

The purpose of this screen is to designate all waste streams containing radioisotopes above the accepted maximum permissible concentration (MPC) levels as hazardous. The actual MPC levels as set by the Atomic Energy Commission (AEC) are in a state of transition; therefore the screen is formulated to accommodate whatever standards exist at the time of the evaluation. Present values are currently under review and may be reduced in the near future. Should this occur, reevaluation of radioisotope-bearing streams may be necessary.

The MPC levels are appropriate for use in a scheme such as this, since they are in part developed to specify discharge levels. Consequently, their use renders the screen compatible with existing AEC regulations and draws on the wealth of research and experience which stands behind the initial selection of those values.

Bioconcentration

The terms bioconcentration, bioaccumulation, and biomagnification are often used interchangeably to describe the phenomenon by which living organisms concentrate an element or compound to levels in excess of those in the surrounding environment. Kneip and Lauer[20] define the three terms in the following manner:

> *Bioconcentration refers to the ability of an organism or a population of many organisms of the same trophic level to concentrate a substance from an aquatic system.*
>
> *Bioaccumulation refers to the ability of an organism to not only concentrate, but to continue to concentrate essentially throughout its active metabolic lifetime, such that the 'concentration factor', if calculated would be continuously increasing during its lifetime.*
>
> *Biomagnification is the term which should be used when a substance is found to exist at successively higher concentrations with increasing trophic levels in ecosystem food chains.*

It should be noted that concentration factor is defined here as the ratio of the concentration of the material of interest in the organism to the concentration of that material in the environment or the preceding link in the food chain.[21]

Employing these definitions, the purpose of the screen is to identify and designate as hazardous those wastes which display a concentration factor in higher organisms, here defined as mammals, fish, birds, mollusks, macrocrustacea, reptiles and amphibians. The screen is not relevant to materials with cumulative effects or materials for which substantial nutritional requirements have been established. In general, bioconcentrated materials as defined here are ones for which the detoxification-excretion mechanism is either non-existent or extremely slow.

Bioconcentrative materials can be grouped into two categories based on retention mechanisms. The first includes the heavy metals such as mercury and lead. These materials, through a strong affinity characteristic with sulfhydryl groups and disulfide bonds, are capable of inactivating or denaturing enzymes and proteins, thus blocking normal metabolic pathways, interfering with control mechanisms and crippling cellular integrity. The second category of bioconcentrative substances is represented by persistent organic materials such as DDT and PCBs. These materials concentrate through an affinity for non-polar solvents and low solubility in water. The contaminants quickly migrate to fatty tissues or lipid cellular fractions where they typically cause hepatic disorders (disorders of the functions of the liver).

Evaulating the data on bioconcentration can be very difficult since no standard bioassay or testing procedure has been adopted by which the bioconcentration potential of a material can be consistently assessed. Present plans call for such a protocol to be developed by the EPA.[47] Until such a standard testing procedure is developed, literature sources documenting environmental build-up of a material or laboratory studies indicating less than complete elimination or detoxification of a material by one of the higher organisms of animal life one week after exposure will be used to select substances under this criterion. This evaluation is presently included in the selection procedure proposed by the Division of Oil and Hazardous Materials (DOHM) of the EPA for designation of hazardous substances. Use of this criterion and any standard testing protocol devised by the EPA will insure compatability with related governmental activities.

Flammability

All waste streams qualifying as Category 4 flammable materials by the National Fire Protection Association[13] will be included as hazardous wastes. Included in the Category 4 flammability rating are

> *very flammable gases, very volatile flammable liquids, and materials that in the form of dusts or mists readily form explosive mixtures when dispersed in air.*

Examples of pure compounds receiving the Category 4 flammability rating are methyl ethyl ether and n-butane. Improper disposal of materials such as these would constitute a public hazard.

Wastes may include a variety of constituents which in combination qualify as Category 4 or whose interactive by-products qualify as Category 4. In practice, wastes may or may not be readily classified utilizing only data on the constitutents in the waste streams. The decision to classify materials as Category 4 is a judgmental one. In general, materials qualify as Category 4 flammables if they are:

1. flammable gases;
2. flammable liquids with boiling points below 100°F and vapor densities ≥1.1 (density is measured as the ratio of the weight of a volume of vapor to an equal volume of dry air under similar conditons);
3. flammable liquids with flash points below 100°F and vapor-air densities ≥1.1; and
4. spontaneously combustible in air.

The vapor and vapor-air density data are meant to account for the hazard of vapors traveling along the ground to an ignition source and then flashing back. This could be a real hazard in landfill operations where heavy equipment exhaust or sparks could ignite escaping vapors. The Category 4 rating is roughly equivalent to a Grade 4 rating on the NAS fire hazard scale.[17]

Reactivity

All waste streams qualifying as Category 4 reactive materials by the National Fire Protection Association[13] will be included as hazardous wastes. Included in the category 4 reactivity rating are those

> *...materials which in themselves are readily capable of detonation or of explosive decomposition or explosive reaction at normal temperatures and pressures.*

Examples of materials in the Category 4 reactivity rating include contaminated benzoyl peroxides and off-spec nitromethane. Improper disposal of materials in this category would constitute a public hazard.

Judging the reactive hazard level of complex wastes will be a difficult task. The major areas of concern will include:

- Detonation by Electrical Shock - Some materials can be detonated by electrostatic charge and as such pose a reactive hazard in various environments. Data pertinent to this hazard can be found in the National Electrical Code (NFPA No. 70)[22].
- Oxidizing Materials - Strong oxidizing agents such as chlorates, perchlorates, bromates, peroxides, nitric acid, nitrates, nitrites, and permanganates are highly sensitive to heat, friction, and impact when in the presence of combustible materials. Mixtures of oxidizing and combustible materials should be considered Category 4 reactive. This would include Grade 4 self-reactive materials in the NAS rating system.[17]
- Polymerization - Certain hazardous wastes are capable of autopolymerization. By-product heat and pressure increases present a danger. Wastes containing materials with this potential should be considered Category 4 reactive. The presence of inhibitors may not be sufficient to reduce the hazard since biological, chemical or thermal action may negate the inhibiting effect. This would include Grade 3 self-reactive agents in the NAS rating system.[17]
- Explosiveness - Wastes containing primary high explosives at any but dilute concentrations should be considered Category 4 reactive. Primary high explosives are defined as those materials which detonate, releasing energy very rapidly and creating very high pressures. Detonation can result from friction, impact, shock or heat. Primary high explosives are rated at 5 inches or less on the Picatinny Arsenal scale.
- Water or Air Reactive - Wastes may also be considered Category 4 if they react violently when exposed to air or water. This would include materials rated as Grade 4 water reactive in the NAS rating system.[17]

Many of these decision factors have not been quantified. The NFPA selection committee relied largely on a consensus approach. Their findings, however, on pure compounds should serve as guidelines for extrapolation to wastes.

Oral Toxicity

Waste streams found to have an oral LD_{50} to man or rats less than or equal to 50 mg/kg body weight are considered hazardous.

The LD_{50} is defined as the dose at which 50 percent of the test population succumbs. The level of 50 mg/kg was selected to comply with existing EPA regulations (40 CFR Section 162.8) and DOT advanced notice of proposed rule making (Docket No. Hm-51, Fed. Reg., Vol. 36, No. 30, February 12, 1971) designating substances either extremely or highly toxic. An LD_{50} of 50 mg/kg or less also matches the NAS toxicity rating of Grade 4.[17] The EPA Division of Oil and Hazardous Materials is also proposing this threshold for designation of hazardous substances.

A large quantity of data on test organisms other than humans or rats and on routes of administration other than oral are available. Often these data may be extrapolated to estimate an oral LD_{50} value for man or rats. Table 3 lists comparative toxic levels outlined by the Department of Health, Education and Welfare[23] which may be used for this purpose.

The oral ingestion route is selected to represent the potential for leaching of landfilled materials into water supplies. Testing procedures for oral toxicity should provide for single dose administration followed by a 14 day observation period. Further information on detailed test conditions can be found in Title 21 of CFR, Section 191.10; the Federal Register, Vol. 36, No. 30, February 12, 1971; and Title 40 of CFR, Section 162.8.

Inhalation Toxicity

Wastes demonstrating an inhalation LC_{50} of 200 ppm or less as a vapor or 2 mg/l or less as a dust or aerosol are considered hazardous. The LC_{50} is the concentration at which 50 percent of the test population succumbs. The levels selected comply with those set by EPA regulations (40 CFR Section 162.8) and DOT advanced notice of proposed rule-making (Docket No. HM-51, Fed. Reg., Vol. 36, No. 30, February 12, 1971) to designate extremely and highly toxic materials. The Division of Oil and Hazardous Materials within the EPA is also proposing this threshold for designation of hazardous substances.

Inhalation toxicity can be of importance for a variety of waste-related activities including vapors escaping from landfills, off gases from combustion processes, and operator exposure during processing, shipment, and disposal. A great deal of information on exposure limits for eight hour working days has been published as Threshold Limit Values (TLV's).[16] While these regulated levels are not of interest in the decision model itself, they are typically estimated on LC_{50} data. These initial toxicological findings should provide an excellent source of data on pure compounds.

TABLE 3

LIMITING DOSAGES DIFFERENTIATING TOXIC AND NONTOXIC SUBSTANCES ACCORDING TO ROUTE OF ADMINISTRATION TO EXPERIMENTAL ANIMALS OF A MAXIMUM SINGLE (ACUTE)[1] DOSE CAUSING DEATH[3]

SPECIES (with list designations)	ROUTES OF ADMINISTRATION (WITH LIST ABBREVIATIONS)								
	Oral (orl) Rectal (rec)	Inhalation (ihl) 8 hr.		Skin (skn)	Intraperitoneal (ipr) Intrapleural (ipl)	Parenteral Subcutaneous (scu) Intradermal (idr) Implant (imp)	Intravenous (ivn) Intramuscular (ims) Ocular (ocu) Intracerebral (ice) Intratracheal (itr)	Other (par)	Unreported (unk)
	mg/Kg	ppm	mg/M	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg
Mouse (mus), Hamster (ham), Frog (frg), Gerbil (grb)	2500	5000	1000	1400	1000	5000	750	1000	2500
Rat (rat), Squirrel (sql) Mammal, unspecified (mam)	5000[2]	10000	2000	2800	2000	10000[2]	1500	2000	5000
Rabbit (rbt) Guinea Pig (gpg), Chicken (ckn), Pigeon (pgn), Quail (qal), Duck (dck), Turkey (trk), Bird (brd)	10000	20000	4000	2800[2]	4000	20000	3000	4000	10000
Dog (dog), Monkey (mky), Cat (cat) Pig (pig), Cattle (ctl), Domestic Animals: sheep, goat, horse (dom)	10000	20000	4000	5600	4000	20000	3000	4000	10000

---

[1] Applies to those substances for which acute toxicity characterizes the response, fast-acting substances, irritants, narcosis-producing substances, most drugs; does not apply to substances whose characteristic response results from prolonged exposure, e.g., silica, lead, benzene, carbon disulfide, carcinogens. Concentrations more appropriately characterizing the toxicity of long- or slow-acting substances are derived from long-term, chronic toxicity studies.

[2] From Hine and Jacobson, Am. Ind. Hyg. Assn. Quart. *15*, 141, 1954.

[3] Calculated from experimental data (Stokinger).

Tests to determine the inhalation toxicity hazards of wastes should be designed around a 24 hour exposure time followed by a 14 day observation period. Further information on testing procedures can be found in Title 40 CFR, Section 162.8; Title 21 CFR, Section 191.10; and the Federal Register, Vol. 36, No. 30, February 12, 1971.

Dermal Penetration

A waste with a dermal LD_{50} of 50 mg/kg body weight or less is considered hazardous. The LD_{50} is defined as the dose at which 50 percent of the test population succumbs. The level of 50 mg/kg was selected to comply with existing EPA regulations (40 CFR, Section 162.8) and DOT advanced notice of proposed rule making (Docket No. HM-51, Fed. Reg., Vol. 36, No. 30, February 12, 1971) designating substances either extremely or highly toxic. The Division of Oil and Hazardous Materials within the EPA is also proposing this threshold for designation of hazardous substances.

The dermal penetration route of administration must be considered since a contact hazard exists both for landfill areas and discharges into surface waters. Data on dermal penetration can be found in classical toxicology manuals as well as in the reports of Smyth, et al.[18,24-30]

Testing procedures for dermal toxicity should provide for one hour of exposure followed by a 14 day observation period. Further details for testing can be found in Title 40 CFR, Section 162.8, Title 21 CFR, Section 191.10; and the Fed. Reg. Vol. 36, No. 30, February, 1971.

Dermal Irritation

Wastes scoring eight or better on the FDA skin irritation evaluation are considered hazardous. This threshold represents moderate or severe edema and erythema on rabbit skins after a 24 hour exposure period. Tests are made on shaved and abraded skin as prescribed in Title 21 CFR, Section 191.1. Additionally, wastes rating Grade 8 or better on the irritation evaluation 10-grade ordinal scale devised by Smyth, et al.[18,24-30] can also be classed hazardous. Here, the material rating is derived as the severest reaction obtained on any of five albino rabbits after a 24 hour exposure of .01 ml of sample or solution in water, acetone, or propylene glycol.

Grade 1 on the above scale indicates no irriation; Grade 2 is evidenced by the least visible capillary injection from the undiluted chemical. Grade 6 indicates necrosis when applied undiluted; Grade 8 indicates necrosis after application of a 1 percent solution; and Grade 10 relates to necrosis from a .01 percent solution. A Grade 8 rating was selected for the threshold because it represents severe irritant effects after a dilution of 100 to 1.

Aquatic Toxicity

A waste displaying a 96 hour TLm of 1000 ppm or less is considered hazardous. TLm refers to the median threshold limit, or the concentration at which a material is lethal to one-half of the test population. A limit of 1000 ppm was selected to comply with thresholds now being proposed by the Division of Oil and Hazardous Materials within the EPA. This justification is based upon concentration levels likely to occur after 1, 3, and 6 hour discharges of tank truck, tank car, and tank barge quantities into various sized streams. Employing a general dispersion model, materials with a 96 hour TLm of 1000 ppm or less may persist at those levels long enough to cause significant damage to aquatic life. Materials with higher TLm values are not likely to cause significant damage. The 1000 ppm or less level correlates with NAS ratings of Grade 2-4 for aquatic toxicity.[17]

Aquatic hazards may result from landfill leachate or direct dumping. The threat is of importance to various fish varieties and fish food organisms.

Testing should follow accepted static or flow-through bioassay techniques for a 96 hour exposure period. Detailed procedures are available in Standard Methods.[31] A great deal of data on aquatic toxicity of pure compounds and wastes has been collected by McKee and Wolfe[32] and by Battelle-Columbus.[33]

Phytotoxicity

A waste displaying an ILm of 1000 ppm or less is considered hazardous. The ILm is defined as the median inhibitory limit, or that concentration at which a 50 percent reduction in the biomass , cell count, or photosynthetic activity of the test culture occurs when compared to a control culture over a 14 day period. The 1000 ppm level was selected for reasons similar to those for selection of the aquatic toxicity threshold.

Plant toxicity is of concern both from the standpoint of damage to commercial operations and damage to aquatic plants which form an important link in the food chain. Plants may be threatened by landfill leachate or direct dumping into surface waters or waters destined for irrigation use.

While no standard testing procedures have been published to date, personnel at the EPA National Environmental Research Center (NERC) in Cincinnati will soon issue a manual containing the necessary testing details.[22] Data on phytotoxicity of pure materials and wastes can be found in McKee and Wolfe,[32] The Water Quality Criteria Data Book, Volume 3[33] and the Oil and Hazardous Materials - Technical Assistance Data System (OHM-TADS) files maintained by the EPA.[34]

Genetic Effects

Wastes found to give positive results to standard genetic effect tests are considered hazardous. Effects may be grouped into three major subcategories:

> Carcinogens - Standard tests for carcinogenic behavior have been promulgated and catalogued by the National Cancer Institute.[35] Any of the accepted procedures described in various NCI publications should be adequate for testing.
>
> Mutagens - Standard mutagen tests have been developed by Weissgunger at the National Cancer Institute.[35] There are also several standardized procedures described by Epstein and Legator.[36] Mutagenic effects in bacterial and plant cultures have never been translated into impact on man, but mutagenesis in any sector of the environment may ultimately be of importance and should be considered hazardous until potential correlations are more clearly defined.
>
> Teratogens - Standard teratogenic potential tests are quite well accepted. They are typically conducted on pregnant New Zealand rabbits. Detailed procedures can be obtained from the National Cancer Institute.

Because genetic effects potential testing is both time-consuming and costly, all wastes should not be subjected to a rigid battery of evaluations. Rather, tests should be required only of those wastes in which known carcinogens, mutagens, or teratogens are known to occur or are strongly suspected of occurring. The National Cancer Institute publishes a list of known carcinogens.[35] Similarly, Epstein has catalogued mutagens.[36] Data on teratogens is somewhat more scattered, but can be found in Volumes 1 and 2 of the Water Quality Criteria Data Book.[37,38] The Department of Health, Education and Welfare also identifies genetic effects potential in their Toxic Substances publication.[23]

This screen should be modified continuously as genetic change potential becomes better understood and as shorter, more reliable tests are developed. Papermeister at Edgewood Arsenal and Shields at Cincinnati are presently developing new testing techniques which could be of major importance.[35]

Application of Model to Waste Streams

The decision model is designed to handle and evaluate waste streams rather than general industry wastes. Consequently, a plant or specific industry may be evaluated for liquid discharges, sludges, solid wastes, and atmospheric emissions. Each of the four waste streams is judged on the basis of its properties and inherent hazards. When separate waste streams, such as two discretely different liquid effluents, are discharged by an industry each is evaluated individually.

If the pitfalls of the pure compound approach are to be avoided, information must be collected on waste streams per se. At the present time there is a paucity of such data. McKee and Wolfe[32] report aquatic toxicity levels for some industrial wastes. Beyond this, no single source of reliable hazard evaluation results exists. This does not invalidate the decision model. Rather, it suggests that alternate means of estimating waste stream hazard data must be employed until such actual numbers are derived. Ultimately, the waste stream data may be obtained by requiring appropriate hazard testing for all plant effluents prior to issuance of discharge permits. Such a requirement would lead to the collection of the necessary data within a few years time. This, coupled with inventories of discharge volumes, would allow much closer observation and control of accumulative environmental effects.

In the interim, however, an alternate method is required. This system must take advantage of existing pure compound data without suffering the pitfalls of the pure compound approach discussed earlier. To do so, it is assumed that all constituents are additive in their effects. This necessitates compound calculations for waste streams. Technical judgments will be needed on the non-quantifiable screens. Estimation procedures for each screening module are described in Appendix A. It must be emphasized that this is not the pure compound approach. It is merely a compromise technique for calculating waste stream data based on existing pure compound data. The decision model is still employed. The only deviation from the recommended model rests in the method of generating the waste stream data. The hazard parameters, such as LD_{50}, are determined mathematically from those of the constituents, rather than experimentally for the waste stream itself.

Clearly, the model will be best employed when comprehensive waste data are required. Regulations can then be structured around the decision model. Initially, wastes qualifying as hazardous under the model will define the boundary of authority. Discharges of wastes so designated can be prohibited. These wastes must then be treated on-site so as to no longer qualify as hazardous or must be routed to a certified hazardous wastes processing and disposal facility. The certified disposal operation is then charged with eliminating the properties that qualified the waste as hazardous or securing it at a properly designated repository.

The model is designed to accommodate changes in regulatory posture, in that thresholds can be set at any level deemed appropriate. Hence, toxic levels can be raised or lowered to reflect new information acquired by Federal agencies and judgmental decisions can be rendered more objective as specific methodologies are derived. It appears essential that any regulatory criteria system adopted for waste materials retain a degree of flexibility. This need derives from the fact that all potential wastes cannot now be identified, let alone their composition detailed. Most will change with time, and the administrative burden in predesignating hazardous wastes would be substantial.

INVENTORY OF HAZARDOUS WASTES

Hazardous wastes both chemical and biological in origin are generated by many of man's daily activities. According to the California Hazardous Wastes Working Group[9]:

> *Included in the category of hazardous wastes are industrial chemicals and sludges; residues of chemicals, paints, dyes, solvents, adhesives, oils, plating and pickling liquors remaining on metal cuttings, sawdust, paper, wood or cloth, or remaining in discarded containers; explosives and flammable materials; fines and dusts from exotic materials; exotic liquids, and acids and caustic liquids and solids; leachings from mineral wastes; leachings from landfills, herbicides and herbicide containers; pesticides, by-products of pesticide production, and pesticide containers; pathological*

> *and infectious wastes, disposable syringes, pills, and drugs from physicians' offices, clinics, hospitals and veterinary facilities; radioactive materials; sewage treatment; and other similar materials.*

Of these, many will qualify as hazardous depending upon the circumstances surrounding their production, the type and degree of treatment they are subjected to prior to discharge, and the extent to which wastes are blended or segregated.

Hazardous wastes may be liquid discharges, sludges, slurries or muds, solid wastes, or atmospheric emissions. During the course of this study the majority of hazardous waste discharges identified were liquid effluents and sludges. This distribution of waste types is not necessarily completely representative of the actual situation. It reflects in part the fact that liquid wastes and sludges have been studied and characterized to a far greater extent than other types of wastes as a result of extensive water pollution-oriented studies conducted over the past twenty years. Atmospheric emissions have come under much finer scrutiny in the last decade, but large areas remain undefined. Extensive studies are needed to identify individual species in various exhausts such as the off-gases from incineration of halogenated aromatics. Solid wastes, tars, and slurries have received the least attention and consequently remain the major unknown.

Regardless of the type of discharge, work identifying individual hazardous constituents, hazardous waste volumes, and the collective hazard of given wastes is nowhere near that required for adequate management of discharges. Booz-Allen Applied Research[10] notes that waste quantification for specific materials does not exist. Among the principal reasons for this situation are:

> *...historically, there has been no interest or objective in quantifying waste amounts of specific materials, with the exception of radioactive wastes, which are subject to a stringent control system;*
>
> *for certain materials, such as pesticides and herbicides, the utilization and disposal cycles were one and the same, but geographic location data were not recorded;*
>
> *in nearly all waste disposal processes, whether industrial, governmental, or domestic, materials being wasted are thrown together and become streams of mixed wastes; and*

pre-disposal waste treatment, where employed at all, has been applied to a limited number of waste stream characteristics, rather than to characteristics of specific materials.

It follows that without waste quantity data for specific materials, geographic location cannot be considered. The impact of the latter two factors above on the hazardous waste quantification problem cannot be overstated. The difficulties imposed can be more succinctly observed when it is noted that mixed waste streams:

- *can have hazardous materials as input;*
- *are not analyzed in detail, if at all;*
- *might be chemically indeterminate, as a result of unknown reactions;*
- *might exhibit some, all, or none of the characteristics of individual input materials; and*
- *might become hazardous in themselves through combinations of nonhazardous input materials.*

Even some of the most recent studies aimed at profiling individual industries fail to identify the potentially hazardous constituents in various waste streams. Rather, they focus on total liquid and atmospheric discharge volumes and broad contaminant indicators such as BOD, pH, suspended solids, turbidity, NOx, and particulates. Such work overlooks many of the more hazardous aspects of wastes and fails to account for by-product sludges, tars, and solid wastes resulting from on-site treatment of effluents.

There can be little doubt that a comprehensive waste inventory is necessary to develop the data required for the proper assessment and management of the hazardous wastes problem. Such an inventory must be based on detailed analysis of waste volumes of all types, their physical-chemical characteristics, and their significant constituents. The data is required on a per industry basis at a seven digit SIC level or better and should include geographical distribution information. Approaches short of these requirements will add little to the sketchy collection of data presently available. Once such an information base has been established, astute use of a discharge permit program should provide a continual update capability.

During the present study estimates of distribution and volume data were collected by Battelle on those waste streams designated as hazardous under the TRW pure compound criteria. These data are presented in Table 4. Detailed data sheets describing the volumes, constituents, concentrations, hazards, disposal techniques, and data sources for each waste stream considered are presented in Appendices C through F. It must be emphasized that these data are gross estimates and do not reflect any on-site treatment or management practices which could significantly alter waste quantities and characteristics. They are, however, the best estimates that can be made at this time. An indication of the degree of confidence that can be placed in each quantity can be obtained from the reference source section of the individual data sheets presented in Appendices C - F. The first column in Table 4 identifies the specific data sheet of interest.

Waste streams from food and kindred products industries were for the most part eliminated from characterization and review. This was justified on the basis that blanching, washing, and flume waters from these plants do not carry highly toxic or hazardous materials. Biochemical oxygen demand and suspended solids are two of the major water pollutants occurring in food processing wastes. Since these problems can be handled by conventional means, these pollutants are not considered hazardous nor difficult to treat. Upon application of the waste stream decision model, caustic peeler wastes may qualify as hazardous until neutralized.

When available, geographic distribution data was derived from plant capacity data developed by Booz-Allen.[10] When this source failed, value added or if necessary total employment figures for a particular industry were obtained from the 1967 Census of Manufacturing Statistics[39] and were used to determine fractional industrial output levels for each region. This data was obtained for the most specific SIC category possible. Typically that was at the three or four digit level. Occasionally, geographic distributions for waste streams resulting from the production of specific chemicals were derived from information contained in the Stanford Research Institute's 1972 Directory of Chemical Producers.[40]

Volume data came from similarly diverse sources. Where possible, data derived by TRW[19] and Booz-Allen[10] were utilized. When these sources failed, waste stream determinate factors were sought. Estimates of waste production per unit of product were solicited from typical producers or trade associations. The procedure employed for deriving each volume figure is specified on the waste stream data sheet under "Ref." in Appendices C through F.

TABLE 4

SUMMARY DATA FOR NONRADIOACTIVE WASTE STREAMS

Aqueous Inorganic Wastes

SIC No.	Waste Stream Title	Page Number	Geographic Distribution - Fraction NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)	
22	Chromate wastes from textile dying	A-297	.101	.178	.034	.005	.568	.034	.014	.060	.006	$2X10^7$	maximum
2812	Chlorine production brine sludges	A-19	.02	.11	.10	--	.19	.22	.24	.12	--	$1X10^8$	
2819	Potassium chromate production wastes	A-301	.19	.06	.015	.005	.60	.10	.01	.01	.01	$1X10^6$	
2821	Cellulose ester production wastes	A-34	.10	.21	.21	.16	.14	.07	.10	.02	--	$5X10^7$	
287	Intermediate agricultural product wastes - nitric acid	A-54	.005	.075	.145	.074	.299	.207	.090	.058	.046	$2X10^5$	
2873	Production works from ammonium sulfate	A-307	--	--	.040	--	--	--	--	--	.96	$1X10^3$	
291	Copper and lead bearing petroleum refinery wastes	A-113	.001	.102	.175	.056	.019	.031	.417	.160	.039	$8X10^8$	
31	Chrome tanning liquor	A-120	.22	.29	.29	.03	.086	.05	.004	.03	--	$2X10^7$	
3231	Mirror production wastes	A-121	.09	.25	.23	.01	.28	.10	.04	--	--	$9X10^6$	
331	Cold finishing wastes	A-307	.03	.34	.43	.01	.07	.02	.05	.01	.04	$5X10^9$	
331	Consolidated steel plant wastes	A-122	.02	.33	.42	.02	.09	.02	.03	.02	.05	$5X10^8$	
3312	Stainless steel pickeling liquor	A-125	.050	.259	.404	.026	.068	.055	.044	.067	.028	$5X10^7$	
333	Brass mill wastes	A-126	.04	.29	.01	.25	.01	.04	.04	.19	.13	$5X10^7$	Cyanide
33	Metal finishing wastes	A-131	.115	.179	.379	.046	.050	.015	.036	.169	.011	$4X10^7$	Solution
	Aluminum anodizing bath with drag out	A-132	.115	.179	.379	.046	.050	.015	.036	.169	.011	$8X10^6$	Metal Sludges
	Brass plating wastes	A-133	.115	.179	.379	.046	.050	.015	.036	.169	.011	Not Available	
	Cadmium plating wastes	A-134	.131	.285	.321	.045	.049	.023	.036	.103	.007	$1X10^6$	
	Chrome plating wastes	A-135	.115	.179	.379	.046	.050	.015	.036	.169	.011	Not Available	
	Cyanide copper plating wastes	A-136	.115	.179	.379	.046	.050	.015	.036	.169	.011	$2X10^6$	
	Finishing effluents	A-137	.115	.179	.379	.046	.050	.015	.036	.169	.011	Not Available	
	Metal cleaning wastes	A-138	.115	.179	.379	.046	.050	.015	.036	.169	.011	Not Available	
	Plating preparation wastes	A-140	.115	.179	.379	.046	.050	.015	.036	.169	.011	Not Available	
	Silver plating wastes	A-141	.115	.179	.379	.046	.050	.015	.036	.169	.011	Not Available	
	Zinc plating wastes	A-142	.115	.179	.379	.046	.050	.015	.036	.169	.011	Not Available	
34	Metal finishing chromic acid	A-143	.244	.198	.149	.095	.081	.032	.031	.031	.041	$4.4X10^7$	
3555	Graphic arts - photography wastes	A-308	.06	.19	.20	.08	.15	.06	.09	.04	.13	$4X10^3$	
36	Electronic circuitry manufacturing wastes	A-148	.143	.342	.170	.037	053	.019	.032	.165	.039	$5X10^5$	
372	Aircraft plating wastes	A-154	.123	.158	.117	.093	.057	.013	.095	.325	.019	$4X10^7$	
	Cooling tower blowdown	A-173	.005	.150	.170	.060	--	.58	--	--	.035	$2X10^7$	(as Chromate)
										Sub Total		$7X10^9$	

TABLE 4 (Continued)

Organic Wastes

SIC No.	Waste Stream Title	Page Number	NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)	
			Geographic Distribution - Fraction										
2818	CoSynthesis methanol production wastes	A-27	--	--	.05	--	.05	--	.90	--	--	1X10^6	Sludge
2818	Formaldehyde production wastes	A-290	--	--	.02	--	.05	--	.93	--	--	8X10^5	Sludge
2818	N-Butane dehydrogenation butadiene production wastes	A-298	--	--	.03	--	--	--	.92	.05	--	3X10^5	Sludge
2822	Rubber manufacturing wastes	A-119	--	.07	.14	--	.11	.11	.50	.07	--	1X10^6	
2879	Benzoic herbicide wastes (DOD)	A-57	.168	.130	.009	--	.447	--	--	.246	--	3X10^3	
2879	Chlorinated aliphatic herbicide wastes (DOD)	A-58	.196	.062	.027	--	.649	--	.010	--	.057	5X10^3	
2879	Phenyl-Urea herbicide wastes (DOD)	A-74	.539	.059	--	--	.343	.059	--	--	--	2X10^3	
2879	Halogenated aliphatic hydrocarbon fumigant wastes (DOD)	A-62	1.0	--	--	--	--	--	--	--	--	2X10^2	
2879	Organophosphate pesticide wastes (DOD)	A-66	.0007	.014	.010	--	.033	--	--	.929	.014	1X10^5	
2879	Phenoxy herbicide wastes	A-78	.0002	.0001	.0007	--	.0008	.849	.149	.0004	.0002	8X10^6	
2879	Carbonate pesticide manufacturing (DOD)	A-55	--	--	--	.006	.848	--	--	.145	--	3X10^2	
2879	Polychlorinated hydrocarbon pesticide wastes (DOD)	A-75 & A-76	.097	.142	.018	.003	.096	.004	.033	.591	.017	1X10^5	
2879	Miscellaneous organic pesticide manufacturing waste (DOD)	A-61	--	.026	.012	.002	.257	--	--	.702	--	3X10^4	
2892	Contaminated and waste industrial propellants and explosives	A-111	--			--	--		--	.655	.344	3X10^5	
2892	Contaminates and waste from primary explosives production	A-99	--	.096	.001	.898	--	.001	--	.001	.003	4X10^6	
2892	Nitrocellulose base propellant contaminated waste	A-101	--	.041	--	.457	.492	--	--	--	.009	9X10^6	
2892	High explosive contaminated wastes	A-98	--	.005	.094	.394	.397	.027	.004	.012	.023	1X10^7	
2892	Incindiary contaminated wastes	A-106	--	--	--	--	--	--	1.0	--	--	6X10^5	
2892	Production of nitroglycerin	A-102	--	--	--	--	.42	.19	--	.39	--	7X10^5	
2892	Solid waste from old primers and detonators	A-104	--	.005	.430	.454	.001	.006	--	.014	.084	3X10^5	
2892	Wastes from production of nitrocellulose propellants and smokeless powder	A-103	--	.060	.046	.387	.477	--	.006	--	.025	6X10^6	
2892	Waste high explosives	A-107	.002	.006	.346	.174	.218	.104	.127	.001	.010	1X10^7	
2892	Waste incindiaries	A-110	--	.014	.002	.002	--	--	.718	.255	.009	8X10^5	
2892	Waste nitrocellulose and smokeless powder	A-108	--					--		.594	.406	2X10^6	
2892	Waste nitroglycerin	A-109	--	--	.01	--	.50	.22	--	.266	.004	5X10^5	
2899	Nonutility PCB wastes	A-51	.037	.221	.372	.153	.040	.041	.057	.072	.009	8X10^6	
2911	Gasoline blending wastes	A-117	.006	.086	.159	.055	.025	.025	.477	.134	.033	4X10^8	
2992	Reclaimers residues	A-118	.040	.120	.205	.081	.135	.082	.139	.155	.044	3X10^8	
3312	Coke plant raw waste	A-124	.02	.33	.41	.01	.07	.02	.06	.02	.06	8X10^7	
9711	Military arsenical wastes	A-159	--	.002	.001	--	.015	.031	.001	.926	.024	3X10^6	
9711	Outdated or contaminated tear gas	A-160	--	.138	.189	--	.022	.044	.252	.209	.144	3X10^8	
										Sub Total		1X10^9	

TABLE 4 (Continued)

Aqueous Organic Wastes

SIC No.	Waste Stream Title	Page Number	Geographic Distribution - Fraction NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)	
2611	Dimethyl sulfate production wastes	A-18	--	x	--	--	x	--	--	--	--	$2X10^5$	Still Bottoms
281	Acetaldehyde via ethylene oxidation	A-26	.015	.170	.156	.047	.156	.111	.265	.060	.020	$8X10^7$	
2821	Residue from manufacture of ethylene dichloride/vinyl chloride	A-35	--	.021	.015	--	.163	.171	.533	.117	--	$2X10^7$	
2822	Nitrobenzene from rubber industry wastes	A-38	--	.07	.14	--	.11	.11	.50	.07	--	$5X10^9$	(probably too dilute to be of concern)
283	Drug manufacturing wastes	A-39	.056	.348	.183	.089	.100	.033	.060	.115	.011	$5X10^9$	" "
2879	Chlorinated hydrocarbon pesticide production wastes	A-59	.115	.148	.136	.073	.141	.057	.093	.183	.054	$2X10^8$	
2879	Miscellaneous organic herbicide production wastes	A-96	.076	.135	.124	.080	.156	.062	.108	.200	.059	$4X10^8$	
2879	Organo-phosphate pesticide production wastes	A-70	.115	.148	.136	.073	.141	.057	.093	.183	.054	$6X10^7$	
2879	Organic pesticide production wastes	A-69	.115	.148	.136	.073	.141	.057	.093	.183	.054	$3X10^8$	
2879	Phenoxy herbicide production wastes	A-97	.076	.135	.124	.080	.156	.062	.108	.200	.059	$4X10^7$	
										Sub Total		$1X10^{10}$	

Aqueous Organic Wastes with Insufficient Quantity or Distribution Data

SIC No.	Waste Stream Title	Page Number	NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)	
2824	Synthetic fiber production wastes	A-37	.046	.121	.101	.018	.404	.182	.101	.027	--	$2X10^{12}$	**ALL SIC 282***
2865	Dye manufacturing wastes	A-48	.015	.170	.156	.047	.156	.111	.265	.060	.020	$1X10^{11}$	**ALL SIC 286***
2879	Nitrile pesticide wastes	A-64	.005	.075	.145	.074	.299	.207	.090	.058	.046	$2X10^{12}$	**ALL SIC 287***
2879	Organic arsenicals from production of cacodylates	A-68	--	.200	.800	--	--	--	--	--	--	**Not Available**	
2879	Torpedo process wastes	A-95	--	--	--	--	--	1.0	--	--	--	Neg.	
49	Utilities and electrical station waste	A-157				Not Available						$3X10^7$	
9711	Wastes from production of chloropicrin	A-52	--	x	--	--	--	--	x	xx	--	Neg.	
										Sub Total		$3X10^7$	

Organic Wastes with Insufficient Quantity or Distribution Data

SIC No.	Waste Stream Title	Page Number	NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)
2491	Spent wood preserving liquors	A-16	.007	.029	.117	.060	.267	.141	.174	.162	.042	Not Available (Vance Air Force Base, OK)
9711	Off spec "agent orange" defoliant	A-168				Not Available						
9711	Paint stripping wastes, Vance Air Force Base, OK	A-169	--	--	--	--	--	--	1.0	--	--	
										Sub Total		Not Available

* Values refer to total liquid discharges for SIC category indicated.

TABLE 4 (Continued)

Solid, Slurry, or Sludge Wastes

SIC No.	Waste Stream Title	Page Number	Geographic Distribution - Fraction NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)	
1021	Recovered arsenic from refinery flues (stored)	A-11	--	--	--	--	--	--	--	1.00	--	$4X10^7$	(Tacoma, WA)
2819	Sodium dichromate production wastes	A-30	--	.150	.243	--	.437	--	.170	--	--	$3X10^8$	
285	Solvent-based paint sludge	A-44	.044	.243	.269	.072	.103	.041	.069	.147	.012	$4X10^7$	
285	Water-based paint sludge	A-45	.044	.243	.269	.072	.103	.041	.069	.147	.012	$3X10^7$	
2869	Tetraethyl and tetramethyl lead production wastes	A-53	--	--	--	--	--	--	.63	.37	--	$3X10^5$	
2873	Urea production wastes	A-305	--	.05	.09	.18	.09	.15	.29	.14	--	$2X10^5$	(Dry Basis)
2879	Benzoic herbicide contaminated containers	A-79	--	--	.655	.154	.006	.017	--	.160	.009	2X104	User
2879	Calcium arsenate contaminated containers	A-80	.03	.02	.08	.07	.16	.16	.35	.03	.09	$6X10^3$	SIC Numbers
2879	Carbonate pesticide contaminated containers	A-81	.0008	.016	.382	.070	.022	.108	.321	.060	.020	$5X10^4$	
2879	Chlorinated aliphatic pesticide contaminated containers	A-82	.381	--	.076	.418	--	.105	.010	.010	--	$1X10^4$	
2879	Dinitro pesticide contaminated containers	A-83	.496	.168	.023	.017	.228	--	.003	.165	.006	$2X10^4$	
2879	Lead arsenate contaminated containers	A-84	.03	.02	.08	.07	.17	.17	.35	.08	.03	$1X10^4$	
2879	Mercury fungicide contaminated containers	A-85	.02	.03	.04	.03	.28	.32	.05	.22	.01	$5X10^2$	
2879	Miscellaneous organic insecticide contaminated containers	A-87	.148	.084	.054	.039	.197	.143	.148	.170	.017	$4X10^4$	
2879	Organic arsenical contaminated containers	A-88	--	.007	--	--	.011	.764	.218	--	--	$5X10^3$	
2879	Organic fungicide contaminated containers	A-89	.048	.125	.047	.028	.441	.001	.036	.266	.007	$8X10^4$	
2879	Organophosphorous contaminated containers	A-90	.043	.050	.018	.125	.139	.192	.175	.208	.049	$1X10^5$	
2879	Phenoxy contaminated containers	A-91	.035	.033	.196	.321	.031	.030	.067	.146	.141	$2X10^5$	
2879	Phenyl-urea contaminated containers	A-92	.106	.085	.106	.033	.106	.424	.042	.095	.003	$9X10^3$	
2879	Polychlorinated hydrocarbon contaminated	A-93	.017	.107	.019	.138	.306	.211	.133	.044	.024	$2X10^5$	
2879	Triazine contaminated containers	A-94	.147	.121	.320	.372	.013	.003	.011	.011	.002	$6X10^4$	
2879	Miscellaneous organic pesticide contaminated containers	A-86	.014	.162	.385	.068	.162	.123	.041	.034	.014	$1X10^4$	
2911	Petroleum refining still bottoms	A-115	.006	.086	.159	.055	.025	.025	.477	.134	.033	$2X10^4$	
2911	Petroleum waste brine sludges	A-116	.002	.06	.09	.011	.12	.10	.55	.045	.022	$4X10^6$	
331	Iron manufacturing waste sludge	A-123	.05	.05	.56	.02	.12	.03	.09	.03	.05	$6X10^6$	
333	Arsenic trioxide from smelting industry	A-127	--	.03	.015	.07	.005	.01	.10	.07	.70	$2X10^7$	
3339	Selenium production wastes	A-128	--	.75	--	--	--	--	--	--	.25	$2X10^4$	
3555	Duplicating equipment manufacturing wastes	A-145	--	1.00	--	--	--	--	--	--	--	$7X10^5$	(Upstate, New York)
3585	Refrigeration equipment manufacturing wastes	A-147	.013	.232	.408	.096	.040	.069	.086	.045	.011	$2X10^8$	
3691	Battery manufacturing waste sludge	A-151	.117	.043	--	.118	.117	--	--	--	.118	$5X10^7$	
49	Arsenic trichloride recovered from coal	A-158	.05	.23	.07	.05	.33	.25	--	--	.07	$6X10^6$	
9711	Military paris green - stored	A-166	--	--	1.0	--	--	--	--	--	--	$3X10^4$	
9711	Stored military mercury compounds	A-170	.47	--	--	.51	--	--	--	.02	--	$2X10^2$	
										Sub Total		$7X10^8$	

TABLE 4 (Continued)

Aqueous Inorganic Wastes with Insufficient Quantity or Distribution Data

SIC No.	Waste Stream Title	Page Number	Geographic Distribution - Fraction NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)
1031	Zinc ore roasting acid wash	A-12				Not Available						Not Available
1092	Mercury ore extraction wastes	A-13	--	--	--	--	--	--	--	.72	.28	Not Available
1099	Cadmium ore extraction	A-14				Not Available						$2X10^8$
22	Mercury bearing textile wastes	A-15				Not Available						Not Available
26	Wastes from pulp and paper industry	A-17	.11	.11	.19	.04	.23	.08	.10	.11	.03	Neg.
28	Cadmium-Selenium pigment wastes	A-46				Not Available						Not Available
28	Waste or contaminated perchloric acid	A-32				Not Available						Neg.
2813	Arsine production wastes	A-25	x	x	x	--	--	x	x	x	--	$1X10^4$
2813	Borane production wastes	A-20	--	1.0	--	--	--	--	--	--	--	Neg.
2813	Nickel carbonyl production wastes	A-21	--	1.0	--	--	--	--	--	--	--	Neg.
2813	Waste bromine pentafluoride	A-24	--	--	--	--	--	--	1.0	--	--	Neg.
2813	Waste chlorine pentafluoride	A-23	--	--	x	--	--	--	x	--	--	Neg.
2813	Waste chlorine trifluoride	A-22	--	--	x	--	--	--	x	--	--	Neg.
2816	Chromate wastes from pigments and dyes	A-49	.015	.170	.156	.047	.156	.111	.265	.060	.020	$1X10^{11}$ ALL SIC 281*
2819	Arsenic wastes from purification of phosphoric acid	A-28	.015	.170	.156	.047	.156	.111	.265	.060	.020	Neg.
2819	Contaminated fluorine	A-29	.007	.101	.166	.075	.147	.207	.147	.096	.054	Neg.
2819	Cyanide production wastes	A-300	.007	.101	.166	.075	.147	.207	.147	.096	.054	$2X10^{11}$ ALL SIC 281*
2819	Waste from manufacture of mercuric cyanide	A-33	--	1.0	--	--	--	--	--	--	--	Neg.
2819	Waste from production of barium salts	A-31	.007	.101	.166	.075	.147	.207	.147	.096	.054	Neg.
2821	Urethane manufacturing wastes	A-36	.046	.121	.101	.018	.404	.182	.101	.027	--	$2X10^{12}$ ALL SIC 282*
2821	Wastes from polycarbonate polymer production	A-302	.046	.121	.101	.018	.404	.182	.101	.027	--	$2X10^{12}$ ALL SIC 282*
283	Pharmaceutical arsenic wastes	A-43	.056	.348	.183	.089	.100	.033	.060	.115	.011	Neg.
283	Pharmaceutical mercurial wastes	A-40	.056	.348	.183	.089	.100	.033	.060	.115	.011	Neg.
2865	Wood preservative wastes	A-47	.007	.029	.117	.060	.267	.141	.174	.162	.042	$2X10^{11}$ ALL SIC 286*
2869	Contaminated antimony pentafluoride	A-50	--	x	x	--	--	--	x	--	--	Neg.
2869	Contaminated antimony trifluoride	A-60	--	x	x	--	--	--	x	--	--	Neg.
2869	Hydrazine production wastes	A-114	x	x	--	--	x	--	x	--	--	Not Available
287	Agricultural chemical production wastes	A-304	.005	.075	.145	.074	.299	.207	.090	.058	.046	$2X10^{12}$ ALL SIC 287*
2879	Agricultural pesticide arsenic wastes	A-56	.005	.075	.145	.074	.299	.207	.090	.058	.046	
2879	Mercuric fungicide production wastes	A-63	.005	.075	.145	.074	.299	.207	.090	.058	.046	
2879	Pesticide arsenate wastes	A-71	.005	.075	.145	.074	.299	.207	.090	.058	.046	
2879	Pesticide arsenic wastes	A-72	.005	.075	.145	.074	.299	.207	.090	.058	.046	
2879	1080 production wastes and contaminated lots	A-77	--	*	--	--	*	1.0	--	--	--	Neg. Production of Sodium Fluoracetate
2879	Wastes from pesticide-herbicide manufacture (arsenites)	A-73	.005	.075	.145	.074	.299	.207	.090	.058	.046	$2X10^{12}$ ALL SIC 287*
2899	Electrical fuse manufacturing wastes	A-112	.037	.221	.372	.153	.039	.040	.057	.072	.009	$2X10^{12}$ ALL SIC 289*
3339	Beryllium salt production wastes	A-130	--	1.0	--	--	--	--	--	--	--	Neg.
3339	Thallium production wastes	A-129	--	--	--	--	--	--	1.0	--	--	Neg. Small amount in Colorado
3555	Rotogravure printing plate wastes	A-144	.105	.446	.320	.051	.019	--	.028	.031	--	$1X10^{12}$ ALL SIC 355*

* Values refer to total liquid discharges for SIC category indicated.

TABLE 4 (Continued)

Aqueous Inorganic Wastes with Insufficient Quantity or Distribution Data (Cont.)

SIC No.	Waste Stream Title	Page Number	Geographic Distribution - Fraction NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)
3573	Computer manufacturing wastes	A-146	.143	.342	.170	.037	.053	.019	.032	.165	.039	$1X10^{12}$ ALL SIC 357*
367	Electronic tube production wastes	A-149	.143	.342	.170	.037	.053	.019	.032	.165	.039	Not Available
3679	Magnetic tape production wastes	A-150	.171	.336	.165	.120	.077	.016	.060	.060	--	$1.1X10^{12}$ ALL SIC 367*
3691	Battery manufacturing wastes	A-152	.030	.236	.289	.111	.103	.029	.056	.134	.012	
3692	Mercury cell battery wastes	A-153	.060	.138	.556	.049	.074	.019	.017	.087	comb.	
40	Railroad engine cleaning	A-155				Not Available						Not Available
40	Arsenic wastes from transportation industry	A-156				Not Available						Not Available
9711	Military cadmium wastes from plating	A-165				Not Available						Not Available
9711	Military sodium chromate	A-164				Not Available						Not Available
										Sub Total		$2X10^{8}$

Solid, Slurry, or Sludge Wastes with Insufficient Quantity or Distribution Data

SIC No.	Waste Stream Title	Page Number	Geographic Distribution - Fraction NE	MA	ENC	WNC	SA	ESC	WSC	W-P	M	Volume (lbs/yr)
011	Wastes from seed industry	A-9	.017	.088	.371	.213	.053	.060	.081	.094	.023	Not Available
0175	Contaminated orchard soil	A-10	.05	--	.15	--	.33	--	.35	.09	.03	Unknown
2879	Old or contaminated thallium and thallium sulfate rodenticide	A-65	.005	.075	.145	.074	.299	.207	.090	.058	.046	Not Available
9711	Highly contaminated soil	A-163	--	--	--	--	--	--	--	--	1.00	$3X10^{9}$ (Stored at Rocky Mt. Arsenal) Not included in total
9711	Spent filter media from military operations	A-167				Not Available						Not Available
9711	Waste chemicals from military	A-171				Not Available						$3X10^{5}$
9711	Explosives from military ordinance	A-162				Not Available						$4X10^{8}$
	Drugs and contraband seized by customs	A-161				Not Available						Not Available
	Etiological materials from commercial production	A-172				Not Available						3X10
										Sub Total		$4X10^{8}$
										Total		$2X10^{10}$

* Values refer to total liquid discharges for SIC category indicated.

Table 5 presents a summary of total estimated quantities of hazardous wastes generated in each of the Bureau of Census regions. In addition to indicating the probable division of treatment plants throughout the U.S., the table suggests that construction of five large and fifteen medium sized hazardous wastes processing plants would require individual plant capacities of one million gallons per day (1.33 million tons per year) and 122,000 gallons per day (.16 million tons per year), respectively.

Once again, it is necessary to emphasize that these quantity figures are not necessarily representative of wastes which might actually be received by a hazardous wastes disposal facility. It would be difficult to predict at this time how the added costs of required treatment might prompt in-plant process changes and on-site treatment attempts. Similarly, there may be significant quantities of "nonhazardous" wastes as designated by the pure compound approach which will in fact be routed to centralized treatment facilities because of treatment complexities or poor on-site treatment economics. More accurate estimates of actual waste volumes to be treated by centralized facilities will become available only after 1) industry has had time to respond to pending hazardous wastes regulations, 2) a comprehensive waste inventory has been accomplished, and 3) the waste stream decision model has been applied to the various wastes to designate those which are hazardous.

Military operations generate some unique wastes which deserve special attention. These materials are discussed below.

DEPARTMENT OF DEFENSE WASTES

Department of Defense-related activities generate an important subcategory of certain hazardous wastes. These stem from the production and packaging of biological agents, lethal and non-lethal chemical agents, and explosives/ordnance.

Biological agents, aside from low-level commercial culture samples, are no longer produced. Stockpiles of biological warfare materials have been demilitarized and destroyed. No major hazardous biological waste management problems remain.

Reportedly, chemical lethal agents are no longer being produced and are presently being demilitarized through a comprehensive incinceration program. By-product brines resulting from these operations present a continuing waste disposal problem. No acceptable methods have been identified to date for the safe disposal of these salts.

TABLE 5

REGIONAL SUMMARY DATA FOR TOTAL QUANTITY OF NONRADIOACTIVE HAZARDOUS WASTES

	Total Identified Quantity (100,000,000 pounds)	Percent Basis
New England	6.3	3.2
Mid Atlantic	45.4	23.1
East North Central	46.8	23.8
West North Central	7.6	3.9
South Atlantic	19.2	9.8
East South Central	10.4	5.3
West South Central	39.9	20.3
West	16.2	8.2
Mountain	4.9*	2.4
Total	196.7	100.0

---

*In addition to these annual amounts, there are 2,600,000,000 lbs of contaminated soil stored at Rocky Mountain Arsenal.

Of the nonlethal chemical agents, only CS is presently being produced. However, large quantities of this and other agents are stored throughout the United States in military and law enforcement facilities. No inventory or monitoring is exercised to maintain close control over these materials. Demilitarization of nonlethal stockpiles is scheduled to take place after completion of work on the lethal agents. Local governmental operations do not generate wastes since their overage and obsolete agents are employed for training purposes.

Explosive/ordnance related wastes from manufacturing operations and obsolete munitions are being studied by an inter-service committee expected to announce findings in March, 1973. Publication is in process, but no release was made prior to June, 1973.

Biological, Chemical, and Explosive Wastes

Wastes and waste streams originating from the munitions activities of the Department of Defense typically originate from production and packaging operations. Additionally, large volumes of product are selected for disposal because of obsolescence, degradation, or planned reduction in stockpiles. These wastes can be divided into three major classifications: 1) those related to biological warfare agents; 2) those pertaining to chemical warfare agents both lethal and nonlethal; and 3) those associated with conventional munitions and explosives.

Biological Agents

All biological warfare agents have been detoxified and product residues have proven to be free of virulent materials. The detoxification program entailed incineration of stockpiled agents and subsequent distribution of the inert ash into soil. Formal reports exist on this matter as reported through U. S. Army channels. The destruction program has been certified and documented according to the Army Munitions Command(AMXDC) Picatinny Arsenal, Dover, New Jersey.

AMXDC indicated that some capability will be maintained at Dugway Proving Grounds, Salt Lake City, Utah, where agents could be produced and tested for defensive purposes only, in such a manner that the agents would be in a contained environment. On completion of any such tests the remaining agent will be disposed of. In the past, Dugway wastes have been managed through a private contractor, Explosives Engineering Corporation, Ontario, California, which has capability for pyrolysis, incineration, detonation, and landfill.[41]

It would appear that biological warfare agents do not presently constitute a major source of hazardous wastes. In light of international agreements disavowing further production or use of these materials, this situation should not change in the near future.

There are also nonmilitary sources of etiological agents which must be considered. It is estimated that annual commercial production of culture specimens reached 15-30 pounds in 1969.[42] These materials are under strict regulatory controls and are not considered to pose a major hazard. Perhaps of more concern is the large volume of biologically active material handled by research laboratories and hospitals. While these facilities typically employ incinerators for destruction of such wastes, there is insufficient knowledge of all the sources and infrequent monitoring of their practices. More study is needed to assess both the actual use of accepted disposal practices and the efficiency of such practices for these low volume sources of hazardous wastes.

Chemical Agents

Chemical warfare agents may be of a lethal or nonlethal nature. Lethal chemical agents include nerve gases, mustards, phosgene, and other materials. Information presently available indicates that all lethal agents will be demilitarized in accordance with plans now being formulated. GB and VX are presently being destroyed under a ten year program. No data are available on the exact amounts of lethal agents to be destroyed.

A basic premise established in the demilitarization of these materials is that they will be rendered "militarily" safe through the Army program. Hence, residues will not contain any detectable levels of lethal agents. However, the product residues in many instances may still possess properties which qualify them as hazardous. AMXDC has indicated that at the present time some processed residues are estimated to be innocuous but must be classified as potentially hazardous because of their origin.

The location of demilitarization centers and quantities of anticipated by-product brine are presented in Table 6. It is estimated that a total of 70,000 tons of salts will ultimately be produced by demilitarization.

A number of studies are underway at Edgewood Arsenal and elsewhere on methods of processing and disposing of lethal agents and their residues. GB, VX, and mustards are now being destroyed with high temperature combustion. A typical

TABLE 6

LOCATIONS AND AMOUNTS OF HAZARDOUS MATERIALS PRESENTLY STORED AT MILITARY ARSENALS

Waste Type	Material	Location	Quantity (tons)
Demilitarization By-Product Brines	Calcium(1) salts of chloride, bisulfate, sulfate, sulfite, carbonate, fluoride and methyisopropyl phosphoric acid(2).	Edgewood Arsenal, MD	3,400
		Pine Bluff Arsenal, AK	7,800
		Rocky Mountain Arsenal, CO	13,000
		Tooele Army Depot, UT	25,000
		Umatilla Army Depot, OR	7,300
		Ansiston Army Depot, LA	5,700
		Pueblo Army Depot, CO	3,500
		Newport Army Ammunition Plant, IN	3,000
		Lexington Blue-Grass Army Depot, KY	900
		TOTAL	70,000
Arsenic Contaminated Soil	Soil contaminated with lime, arsenic, oxide, arsenic chloride, mercury halide salts, some inorganic fluoride and chloride.	Rocky Mountain Arsenal, CO Basin A	1,300,000
Chlorinated Hydrocarbon Contaminated Soil	30% organics - chlorinated hydrocarbons, halo-organic phosphorus, mercaptans, parathion insecticides, phenolics, phosphorus acids, sulfonated detergents, urea; 70% inorganics aluminum chloride ammonium chloride, ammonium phosphate, calcium sulfate, carbonate, chloride, fluoride, nitrate, phosphate, sodium nitrate, sulfate, sulfite	Rocky Mountain Arsenal, CO Basin F	750,000

(1) All arsenals will discharge these salts in the calcium form except the Rocky Mountain Arsenal.
(2) Methylisopropyl phosphate salts will be present only at the Rocky Mountain Arsenal.

operating procedure calls for incineration at three to six pounds per minute for a 1000 minute day. Scrubber solutions are concentrated to a 40 percent slurry (by weight) before being spray dried. The composition of dry salt residues resulting from the disposal of various agents are given in Table 7.

No satisfactory solutions for the ultimate disposal of residue salts have been developed. It appears that attempts are being made to utilize and convert existing personnel and facilities from military R&D to demilitarization R&D. AMXDC reports that environmental impact statements have been approved on all demilitarization programs.

Since GB, VX, and mustards are no longer manufactured, no production waste streams requiring treatment are expected in the near future.

Nonlethal chemical agents include materials designated CN, CS, DM, FS, mixtures of these, smokes, and pyrotechnics. CN is considered obsolete and is presently being phased out. Precise estimates of the size of stockpiles of these agents are difficult to calculate since small inventories of many of these agents are dispersed throughout the United States in warehouses of military and law enforcement facilities. There is no close control over or monitoring of the locations of these agents except for arsenicals which have been restricted to three major storage sites, one of which is Edgewood Arsenal.

Of the riot agents, only CS is presently being produced, and by-product wastes from that operation are disposed of on-site. Blending and packaging operations are completed at a number of GOCO (government-owned, contractor-operated plants) sites such as the Pine Bluff Arsenal and possibly by a limited number of private contractors. Wastes generated in packaging nonlethals include residues from spills, rejects, empty containers, and washdown. It is estimated that 12,000 pounds per year of CS agent in 72 x 10^6 gallons of water is wasted. Present plans call for collection of these aqueous discharges and chemical destruction of the active agent prior to clarification and dewatering in lagoons.[43]

Due to the limited shelf life of many of these agents, periodic performance assurance tests must be made on each packaged agent. The fumes from such tests will be passed through afterburners and a scrubber mechanism. Munitions found to be unsatisfactory will be disposed of in an incineration system similar to one developed for demilitarization of lethal agents. Experimental programs planning for the aforementioned facilities are in progress at Edgewood Arsenal.

TABLE 7

COMPOSITION OF SALT RESIDUES FROM DEMILITARIZATION OPERATIONS

Mustard Incineration at Rocky Mountain Arsenal

Sodium sulfite	40%	Sodium bisulfate	3%
Sodium chloride	40%	Iron oxides	2%
Sodium bicarbonate	10%	Sodium carbonate	Trace
Sodium sulfate	5%	Sodium sulfide	Trace

Mustard Incineration at Tooele Army Depot
Transportable Disposal System

Calcium sulfite · $2H_2O$	70%
Calcium chloride · $2H_2O$	30%

Incineration of GB* (Calculated by Contractor)

Calcium phosphate	80%
Calcium fluoride	20%

Incineration of VX* (Calculated by Contractor)

Calcium phosphate	28.5%
Calcium nitrate	40.2%
Calcium sulfite · $2H_2O$	31.3%

---

* The furnace and scrubber systems used for GB and VX incineration are proprietary processes developed by the contractor.

When and if the 29,000 pounds of DM (an arsenical) located at Edgewood and other bulk or stored amounts of this material are destroyed, scrubber solution disposal will be complicated because of the presence of arsenite and arsenate salts. This problem has not been addressed to date.

In addition to process wastes and degraded agents, there are stocks of nonlethal bulk and packaged materials which must be disposed of. The volumes of these materials presently scheduled for disposal by the Department of Defense are included in Table 8.

Disposal of nonlethal obsolete bulk agents and ordance at Pine Bluff Arsenal will be accomplished in a demilitarization program under the U. S. Army Munitions Command, Joliet, Illinois. Actual treatment and disposal processes for that program have been outlined in a comprehensive report produced by Envirotech Systems, Inc.[44]

Information reported by TRW Systems, Inc.[19] and obtained from the California Department of Justice and a major riot control device manufacturer indicates that there are no local government waste disposal requirements for overage and obsolete control devices/agents. It is believed that most local governmental law enforcement agencies use all of these materials for training exercises.

Explosive/Ordnance

Wastes generated by explosive and ordnance related activities stem from production; load, assembly, and pack operations; and overage or obsolete stockpiles of materials from any of the following six categories:

- initiating agents and primers;
- boosters;
- propellants, nitrocellulose base;
- propellants, composites;
- high explosives; and
- contaminated solid wastes.

The task of developing an explosive/ordnance destruction program has been assigned to an inter-service committee, the Joint Committee on Disposal Ashore, which was to make its recommendations known in March, 1973, through the Navy.

TABLE 8

OBSOLETE CONVENTIONAL MUNITIONS
HAZARDOUS MATERIAL CONTENTS AND GROSS WEIGHT
* DISTRIBUTION BY STATE--SCHEDULED FOR DISPOSAL BY THE DEPARTMENT OF DEFENSE

		WEIGHT OF EXPLOSIVE, INCENDIARY, PYROTECHNIC AND RIOT CONTROL AGENT FILL, POUNDS							WEIGHT OF OBSOLETE MUNITIONS CONTAINING EACH FILL CATEGORY, POUNDS						
	TOTAL %	(1)	(2)	(3)	(4)	(5)	(6)	TOTAL	(1)	(2)	(3)	(4)	(5)	(6)	TOTAL
ALABAMA	2.26	900	539.664		1,118,677	6,802	15,666	1,681,709	3,446,600	3,727,600		3,095,600	564,600	32,400	6,812,800
CALIFORNIA	4.32	23,608	1,327,982	159	621,303	128.819	2.595	2,104,466	9,423,300	10,984,700	1,200	9,882,600	358,300	12,100	13,002,000
COLORADO	3.01	2,210	962,052		317,692		81	1,282,035	8,403,000	8,403,000		9,073,800		200	9,073,800
FLORIDA	0.0064	1	812		397	38		1,248	1,400	6,700		2,600	111		19,300
GEORGIA	0.0000086					11		11					26		26
HAWAII	1.64	4,151	265,317	49	1,879,438	63,179	104	2,212,238	157,000	1,535,800	4,700	3,172,000	195,200	1,500	4,954,200
ILLINOIS	6.73	47,856	1,059,183		752,641			1,859,410	19,157,800	19,114,200		19,192,600			20,288,600
INDIANA	12.19	16,790	6,086,532	15	6,678,784	416,618	186	13,198,925	7,916,100	22,694,000	30,000	20,581,392	7,340,700	320	36,722,200
KENTUCKY	2.17	1,921	855,000		302,314		37,971	1,197,206	6,243,200	6,243,200		6,385,000		82,800	6,554,000
MARYLAND	0.021	17	15,617		20,304			35,938	35	25,200		37,600	81		63,300
NEVADA	16.50	93,670	3,964,246	117	12,824,056	774,514	7,610	17,664,213	4,060,300	15,330,300	7,600	25,049,800	2,443,600	63,000	48,369,400
NEW JERSEY	0.89	6,454	207,706	49	524,258		440	738,907	699,400	957,800	900	1,612,200	660,500	1,200	2,686,700
NEW YORK	2.44	6,786	1,238,392		735,751			1,980,929	2,490,000	6,588,600		3,247,200			7,363,800
NORTH CAROLINA	0.0063	5,000			2,808	21		7,829	12,500			5,200	31		19,100
OKLAHOMA	24.00	35,654	13,997,459	394	6,479,680	911,987	952	21,426,126	35,121,200	54,440,200	786,000	46,565,400	34,482,800	1,300	69,542,500
OREGON	6.35	4,396	1,937,082		1,353,290		946,944	4,241,712	16,642,400	16,642,400		17,107,000		2,486,000	19,128,400
PENNSYLVANIA	10.50	11,398	3,459,496		2,485,059			5,955,953	28,515,800	24,423,000		29,202,000			30,267,000
RHODE ISLAND	0.00027					34		34					79		81
SOUTH CAROLINA	0.58	1,143	177,665		314,027	94,331	113	587,279	79,700	713,100	232	864,400	217,700	226	1,752,100
TEXAS	1.22	7,936	407,675		113,149	433		529,193	3,632,200	3,674,200		3,468,200	130,135		3,674,300
UTAH	1.34	1,099	478,181		129,238			608,518	4,037,400	4,037,400		4,037,400			4,037,400
VIRGINIA	1.59	32,002	399,348	176	658,333	178,545	4,795	1,273,199	395,600	1,701,800	2,600	1,967,500	349,200	9,200	4,782,500
WASHINGTON	2.09	2,022	447,479	7	1,463,890	7,915	176	1,921,48c	52,300	2,797,000	800	2,874,100	40,200	360	6,310,700
CONTINENTAL UNITED STATES	99.85	305,014	37,821,828	966	38,775,092	2,942,303	1,017,633	80,862,836	150,487,300	204,004,200	834,000	207,405,500	46,783,200	2,690,600	301,237,344

CODE: (1) INITIATING AGENTS AND PRIMERS; (2) PROPELLANTS, NITROCELLULOSE BASED; (3) PROPELLANTS COMPOSITE/OTHER; (4) HIGH EXPLOSIVES; (5) PYROTECHNICS AND INCENDIARIES; (6) RIOT CONTROL AGENTS

* WILL NOT AGREE WITH SUM OF WEIGHTS OF OBSOLETE MUNITIONS CONTAINING THE INDIVIDUAL FILL CATEGORIES BECAUSE OF REDUNDANCIES DUE TO MULTIPLE FILLS IN MANY ORDNANCE ITEMS. U.S. ARMY - AS OF 28 JULY 1972; U.S. NAVY - AS OF 30 NOVEMBER 1972

Preliminary findings have been forwarded to EPA[45] but are not a matter of public record.

The locations and total quantity of obsolete conventional munitions scheduled for disposal are presented in Table 8. Statistics on explosive manufacturing wastes appear in Table 9.

Several unique problems have also been identified during this review program. Various sources have indicated that individual or groups of hazardous materials were buried either accidentally or under wartime pressure in numerous locations. Many of these repositories are not documented and may be lost for all practical purposes.

Similarly, there are large volumes of hazardous waste-contaminated soil in two basins at Rocky Mountain Arsenal as identified in Table 6. In addition, some buildings at this site have been contaminated with nerve gas from long periods of exposure which resulted in absorption of the agent into the walls. Those construction materials involved represent a special disposal problem.

PRIORITY OF CONCERN

In addition to selection and quantification of criteria designating certain hazardous wastes, it is obvious that, given the potentially wide range of candidate wastes, it would be highly desirable to develop a system for ranking these wastes in terms of their existing or potential threats to public health and/or the environment. Such a ranking system would call attention to problems of imminent concern requiring regulatory or enforcement emphasis and development of new management techniques or additional study and development.

It is essential that a clear distinction be made between development and application of criteria for designating hazardous wastes and development and application of a priority ranking system, despite the fact that in each case similar or related data must be manipulated. In Battelle's view, the designation criteria relate solely to the intrinsic hazard of the waste itself on uncontrolled release to the environment, regardless of quantity, pathways to man or other critical organisms, or other factors. Thus only such factors as vertebrate and invertebrate toxicity, phytotoxicity, genetic activity, and bioaccumulation are involved in development of the designated criteria.

TABLE 9

EXPLOSIVE MANUFACTURING WASTES - POUNDS PER YEAR SOLID WASTES

STATE	INITIATING AGENTS AND PRIMERS				PROPELLANTS, NITROCELLULOSE BASE				PROPELLANTS, COMPOSITE/OTHER				HIGH EXPLOSIVES				PYROTECHNICS AND INCENDIARIES				TOTAL
	SCRAP EXPLOSIVE		CONTAMINATED INERTS		SCRAP EXPLOSIVE		CONTAMINATED INERTS		SCRAP EXPLOSIVE		CONTAMINATED INERTS		SCRAP EXPLOSIVE		CONTAMINATED INERTS		SCRAP EXPLOSIVE		CONTAMINATED INERTS		
	%		%		%		%		%		%		%		%		%		%		
MASSACHUSETTS													0.16	22,000							22,000
CONNECTICUT																	1.40	11,000			11,000
NEW YORK	0.006	200	0.010	400									0.15	20,500			0.19	1,500			23,000
NEW JERSEY	0.36	1,100	5.90	237,000	6.04	365,000	4.14	365,000					0.053	7,300							975,000
PENNSYLVANIA	0.16	500	3.78	152,000									0.371	51,300	4.93	577,000					781,000
VIRGINIA	0.0033	10			47.49	2,871,000	49.23	4,344,000					21.81	3,012,000	39.65	4,636,000					14,863,000
WEST VIRGINIA					0.18	11,000															11,000
ALABAMA	0.59	1,800	0.017	700									0.16	22,000	0.62	73,000					98,000
TENNESSEE	0.0033	10											10.28	1,419,000	2.08	243,000					1,662,000
LOUISIANA					0.61	37,000							11.90	1,643,000							1,680,000
ARKANSAS																	69.98	548,000	100	639,000	1,187,000
TEXAS													0.80	110,000	0.38	44,000	1.86	14,600			169,000
ILLINOIS					2.18	132,000							28.23	3,898,000	9.37	1,095,000					5,125,000
WISCONSIN					2.33	141,000							5.29	730,000							871,000
OHIO	0.20	600	0.0050	200									0.085	11,800	0.0026	300					13,000
INDIANA	43.40	132,000			0.061	3,700							0.96	133,000							269,000
MISSOURI					3.62	219,000							1.61	222,000	0.62	72,300	0.15	1,200			513,000
NEBRASKA					3.62	219,000	0.68	60,200					1.59	219,000	0.51	60,200					558,000
KANSAS	45.38	138,000	89.95	3,614,000	31.05	1,877,000	45.09	3,979,000					0.99	138,000	30.91	3,614,000					13,369,000
IOWA													13.17	1,819,000	7.37	862,000					2,681,000
MINNESOTA					0.36	21,900															21,900
ARIZONA													0.027	3,700							3,700
UTAH					2.45	148,000	0.86	76,000	40.60	713,000	34.53	115,000	0.027	3,700	0.78	91,300	25.54	200,000			1,347,000
COLORADO	0.0033	10	0.045	1,800									0.027	3,700							5,500
NEW MEXICO	8.48	25,800	0.26	10,300									0.91	126,000	0.43	50,000					212,000
CALIFORNIA	1.35	4,100	0.035	1,400					59.40	1,043,000	65.47	218,000	0.021	2,900			0.87	6,800			1,276,000
WASHINGTON													1.39	192,000	2.34	274,000					466,000
	99.99%		100.00%		99.99%		100%		100%		100.00%		100.00%		99.99%		99.99%		100%		
TOTAL		304,000		4,018,000		6,046,000		8,824,000		1,756,000		333,000		13,810,000		11,692,000		783,000		639,000	48,205,000

In contrast, in the development of a priority ranking system it is obvious that the net potential threat to public health and environmental quality of a given waste is strongly dependent upon the quantity of the waste involved, the extent to which present treatment technology and regulatory activities mitigate the threat, and the pathways to man or other critical organisms (that is, the rates and routes of the intrinsic hazard to the point where damage can be manifested).

Comparison of magnitudes of threats posed by hazardous wastes is difficult. It requires input on the inherent hazards of the wastes, the quantities of wastes produced, and the ease with which those hazards can be eliminated or circumvented. The following approach is designed to combine these inputs into a final numerical factor, the relative magnitude of which will determine the priority-of-concern.

The final numerical factor is designed to represent the volume of the environment which could be potentially degraded to a critical level by a given waste. The assumption is made that all sectors of the environment are equally valuable so that a unit volume of soil is as important as a unit volume of water or air. This simplification does not reflect the fact that atmospheric and aquatic contaminants are in general more mobile than terrestrial ones but does recognize the problem of environmental transfer from one phase to another.

The numerical factor is derived by dividing the volume of a waste by its lowest critical product. This may be expressed mathematically as

$$R = \frac{Q}{CP}$$

where

R = ranking factor;
Q = annual production quantity for the waste being ranked;
CP = critical product for the waste being ranked.

A critical product is the lowest concentration at which any of the hazards of concern become manifest in a given environment multiplied by an index representative of the waste's mobility into that environment. Hence, for a waste which will be discharged to water or to a landfill where leaching will occur, the product might be the 96 hour TLm to fish for that waste (e.g., 1 mg/l) multiplied by its solubility index. The solubility index is defined as a dimensionless number between 1 and ∞ obtained by dividing 10^6 mg/l by the solubility of the waste in mg/l. A waste soluble in water to 500,000 mg/l has a solubility index of

$SI = 10^6/5x10^5 = 2$

This presumes that all wastes miscible in water or soluble to more than 1,000,000 mg/l will have similar mobility patterns and thus should receive a maximum index of 1. The critical product for the example waste would then be:

CP = 96 hr TLm X SI

CP = 1 mg/l X 2 - 2 mg/l

Similarly, for atmospheric pollutants the critical product might be the LC_{50} multiplied by the volatility index. This index would be derived by dividing atmospheric pressure under ambient conditions by the vapor pressure of the waste. Potential for suspension of dusts in air would be given a mobility index of 1. Potential for suspension of particulate matter in water would also be given a mobility index of 1 if dissolution subsequently occurs, or if the hazard is related directly to suspended particles.

The aqueous and atmospheric environments are of greatest concern since discharge to the land represents major hazards in the form of volatilization of wastes or leaching. Where data are available on phytotoxicity or other hazards related to direct contact with wastes in soil, the critical product for ranking would be derived from use of the critical concentration at which the hazard becomes apparent and a mobility index of 1.

As with the waste stream decision model, actual waste stream data is most desirable for use in the priority ranking formulation. However, since such data are generally lacking, the additive estimations recommended for interim use can be employed for priority ranking until waste stream data become available.

Ranking numbers thus derived have a physical significance as well as an ordinal one. Because the mobility index is dimensionless, R has the units of volume per year. It represents the actual volume of the sector of the environment of interest critically degraded each year by a given waste. A thorough discussion of the critical concentration concept and its use in ranking formulations can be found in reference 12.

Should it appear advisable to produce a ranking reflective of regulatory status or future treatment requirements, a modification of the basic formulation can be made by adding a new factor, E, where

E = regulatory efficiency or projected treatment status so that

$$R = \frac{QE}{CP}$$

The new factor modifies the ranking to reflect exterior changes. That is, if current regulatory status is of interest, E becomes a fractional parameter such that for well regulated wastes, $E \rightarrow 0$ and for unregulated wastes $E \rightarrow 1$. This then puts the ranking in the perspective of existing control regimes. Similarly, the impact of "best available" and "best practicable" treatment limitations can be introduced into the formulation through proper selection of an E factor that relates to the efficiency of these processes.

If wastes A and B were ranked, the procedures would be as follows:

	Waste A	Waste B
Annual Waste Volume	10^6 lbs	10^5 lbs
96 hr TLm	25 lbs/mil. gal.	0.1 lbs/mil. gal.
Solubility	350 ppm	200 ppm
Regulatory Efficiency	0.4	0.2

For Waste A:

$$R_A = \frac{Q_A E_A}{CP_A}$$

$$= \frac{Q_A E_A}{TLm_A \ SI_A}$$

$$= \frac{10^6 x0.4}{25x10^6/350}$$

$$= \frac{0.4x350}{25}$$

$$= 5.6$$

For Waste B:

$$R_B = \frac{Q_B E_B}{CP_B}$$

$$= \frac{Q_B E_B}{TLm_B \; SI_B}$$

$$= \frac{10^5 x 0.2}{0.1 x 10^6/200}$$

$$= 0.2x200$$

$$= 40$$

B, therefore, is considered to be the more pressing problem. Even though B is already regulated twice as well as A (.2 vs. .4) its greater toxicity (0.1 vs. 25) threatens a larger portion of the environment each year (40 million gallons vs. 5.6 million gallons).

Flammable and explosive wastes do not fit well into such a formulation. It would appear advisable, however, to treat them differently in any case. If the hazard posed by one of these wastes is one of safety to operators at the plant, then control of those hazards falls within the scope of the Occupational Safety and Health Act (OSHA). Flammable and explosive wastes are a concern under the Resource Recovery Act only if they are stored or buried and thus are a latent hazard to the general public. This hazard can be avoided by requiring destructive disposal of all hazardous wastes so designated solely because of the explosive sensitivity or flammability. This is reasonable since these materials can normally be incinerated or detonated safely. Such action would prevent casual public exposure and inplant control would remain with already empowered authorities.

The ranking system recommended here parallels closely one employed by EPA's Division of Oil and Hazardous Materials (DOHM) for spotlighting hazardous materials posing the greatest threat to the environment from accidental spills.[12] Application of such a system for waste streams, however, will be more difficult since the data required are not as readily available. While the DOHM system employs an additional probability parameter to measure potential for spills along waterways, the recommended system includes a functional variable E designed to modify rankings according to the immediate situation.

The formulation accounts for treatability by addressing itself to actual plant discharges rather than raw wastes. Hence, if a chromate-containing waste stream is typically reduced to a chromate sulfate sludge and "clean" effluent, the two resultant discharges can each be evaluated using their individual volumes and revised hazard levels. The clean effluents may no longer qualify as hazardous and hence require no priority rating. The chromic sulfate sludge, while still potentially hazardous, will receive a much lower ranking because of its insolubility. This approach considers the waste treatment facilities of an industry as part of the overall plant and examines only emissions in the states and quantities which actually leave the plant.

The present effort did not include attempts to gather all the data necessary to rank certain hazardous wastes in accordance with the formulation derived here. In many cases the concentration and volume data are insufficient at the present time to allow such an endeavor. Hopefully, this situation will be remedied with the collection of comprehensive waste inventory data in the near future.

CHAPTER CONTENTS

CHAPTER IV

HAZARDOUS WASTE MANAGEMENT METHODS AND COSTS

	Page No.
BRIEF	83
DESCRIPTION OF SITE TYPES	84
Hazardous Waste Processing Facility	84
Hazardous Waste Disposal Facility	85
PROCESS SELECTION	85
Potential Processes	85
Selected Processes	85
Treatment and Disposal	88
Chemical Treatment	88
Ammonia Stripping	90
Organic Removal	90
Evaporation	90
Incineration	91
Disposal Processes	91
PROCESS DESIGN	91
Treatment Facility	91
Receiving, Segregation, and Storage Module	93
Ammonia Stripping Module	95
Chemical Treatment Module	101
LIQUIDS-SOLIDS SEPARATION MODULE	107
Carbon Sorption Module	115
Incinerator Module	115
Evaporation Module	118

Preceding page blank

TABLE 23 (continued)

Waste Stream	Total Annual Curies	Annual Production	Curies of Radioactive Constituents
Reprocessing, Solid - Conglomerate Solids and Solidified Liquids (b)	$1.8X10^6$	$2.0X10^5$ ft^3	Major Constituents: Sr 89-90, $4X10^4$; Y 91, $3.7X10^4$; Zr-Nb 95, $1.8X10^5$; Ru 103-106, $1.1X10^5$; Cs 134-137, $7.2X10^4$; Pm 147, $2.3X10^4$; Ce 141-144, $1.9X10^5$; Pu 238, $1.8X10^4$; Pu 241, $1.1X10^6$
Reprocessing, Solid - Cladding Hulls with Five Years of Decay	$4.2X10^6$	$2.0X10^4$ ft^3	Major Constituents: Mn 54, $1.5X10^4$; Fe 55, $6.4X10^5$; Co 60, $3.1X10^6$; Ni 63, $3.9X10^5$; Sb 125, $1.5X10^4$
Reprocessing, Solid - High Level Actinide Containing Wastes with Five Years of Decay	$1.3X10^8$	$1.5X10^3$ ft^3	Major Constituents: Sr 90, $3.4X10^7$; Cs 134-137, $6.7X10^7$; Pu 238, $7.2X10^3$; Pu 239, $8.6X10^2$; Pu 240, $1.2X10^3$; Pu 241, $2.2X10^5$; Am 241, $8.6X10^4$; Am 243, $8.6X10^3$; Cm 244, $1.3X10^6$; Eu 154, $2.8X10^6$; Sb 125, $1.1X10^6$; Pm 147, $1.4X10^7$; Eu 155, $4.3X10^5$

(a) Production estimated from isotopic specific radioactivity of U-238

(b) Volume primarily conglomerate solids which is mostly paper and plastic the attached work sheets was derived from Federal Regulation 10 CFR 20.304 for the disposal of radioactive material by burial in soil.[99] As discussed earlier, the bases for liquid and gaseous waste effluents are taken to be those in the proposed Appendix I to Federal Regulation 10 CFR 50:

> *...to provide numerical guides for design objectives and technical specification requirements for limiting conditions for operation for light-water-cooled nuclear power reactors to keep radioactivity in effluents as low as practicable."*[106]

Although this regulation is only proposed and the final values may be changed, indications are that the final values will be comparable to those selected.

More specifically, selection of prospective waste streams from the nuclear fuel cycle to be handled under a national system* was based on the following criteria.

- Solid Wastes

  Wastes would be disposed of at national disposal/storage sites from any source site or individual facility if the annual curie content was estimated to be greater than 50 times the amount specified in Appendix C, 10 CFR Part 20. (This factor was derived by using the limits of radionuclides which could be buried at each site [or 1,000 times those in Appendix C] divided by an assumed plant life expectancy of 20 years to obtain the annual allowable rate of burial at each site.)**

---

*The term "national disposal site" refers to the site of the facility conceptually designed in this report and operated as part of a national waste disposal system. The disposal site includes a national repository for storage of solidified wastes and an accompanying waste processing facility if such is required.

**It is believed that these provisions of 10 CFR 20 should receive special study. The provisions allow for the burial of curie quantities of radionuclides at a user's site.

- Liquid Wastes

  Wastes would be disposed of at national disposal sites from any source site or individual facility if the annual curie content, excluding tritium, was estimated to be greater than five, and/or if the annual average concentration of tritium prior to dilution in a natural body of water was estimated to be greater than 0.005 microcuries per liter.

- Gaseous Wastes

  National disposal sites would be required for disposal of radioactive contaminants from any source site if the annual average exposure rate from noble gas effluents was estimated to be greater than 10 millirems and/or the annual average concentrations of radioactive iodines or radioactive material in particulate form with a half-life greater than eight days was estimated to be greater than 10^{-5} times the amount specified in Appendix B, Table II, Column I, 10 CFR Part 20.

  Typical volumes of water and air effluents from nuclear facilities were used to convert these concentration bases to allowable annual discharges.

Review of the bases in conjunction with the information previously summarized in Table 21 and presented in the work sheets in Appendices C-F revealed the following:

- All solid waste streams would require disposition to national disposal sites. However, special consideration must be given the solid waste stream from uranium mining and milling. Currently, solid wastes from milling and conversion to U_3O_8 are, for the most part, impounded or stored in abandoned piles of "mud". Very large quantities are involved; Reference 137 predicts that 4 million tons of mill tailings will be generated in 1980. This study has led to the conclusion that these wastes should not be removed. However, disposition of these wastes should be determined in the reasonably near future. Assuming proper processing techniques, hydrology and geology, it is conceivable that these wastes could be "fixed" in place to keep them from man's environment and that current source sites could become disposal sites. It should also be noted that the radioactivity estimated here for the mill tailings is only 2 x 10^{-9} curies per gram or about two-thirds of that associated with typical uranium ores.

- The radioactivity of the liquid wastes from fuel fabrication, irradiation, and reprocessing exceeds the values selected for the bases by at least several fold.* It is expected that all such wastes will be treated so that they become releasable to surface waters, and the remaining radioactivity will be incorporated into a solid before disposal within a national system. An exception would be release of tritium as a gas or vapor to the atmosphere. Therefore, in the preparation of Table 22, all the radioactivity shown in Appendix C work sheets was assumed to be included in solid waste streams except for the tritium radioactivity.

- The review indicated that the radioactivity of the gaseous wastes would probably be below the values specified for recovery and storage or disposal. The basis for the site average annual atmospheric "dilution factor" for reactors was taken as the best dilution factor from 17 existing nuclear reactor sites. For fuel reprocessing plants, the dilution factor was taken as near-best for the three existing and planned plants. It should be noted that currently unsettled interpretations related to radiation dose to a person's skin from noble gases and unfavorable site dilution characteristics could possibly require recovery of Kr-85 from fuel reprocessing plants by 1980 (with conversion to a waste to be stored).

Because of the limits of Appendix C, 10 CFR 20, most wastes from the nuclear fuel cycle would require off-site disposal. It was assumed for Table 23 that all radioactive wastes from nuclear power plant sites, and essentially all of the low-level trash from fuel fabrication and reprocessing plants, would be buried at sites designated within the national system regardless of contamination level. It is believed that any conversion to solids of the radioactivity content in those liquid streams would not significantly alter the solid volume projections presented in Table 21 (which were estimates for the relatively large volumes of solid wastes from other sources).

---

*The liquid volumes were taken as those from the Nuclear Fuel Services reprocessing plant and the Trojan Nuclear Power Plant.

RADIOACTIVE WASTES FROM MISCELLANEOUS PRIVATE SOURCES

Radioactive wastes other than those from the nuclear power industry, DOD, and AEC prime contractors result from a variety of sources including radiation source fabricators, pharmaceutical companies, chemical companies, hospitals, universities, and instrument manufacturers. These wastes listed in Table 24 vary widely in both composition and radioisotopic content.

The amount of radioisotopes produced by miscellaneous private companies was estimated at 3,000,000 curies (mainly Co-60) by J. N. Maddox of AEC Headquarters. Mr. Maddox pointed out that specific information on private production may be proprietary.

The compositions and quantities of wastes were obtained from Reference 112. Estimation of the probable fraction of radioisotopes showing up in solid or liquid wastes was based on usage and processing information.[140]

The amounts and kinds of radioisotopes to be sold in 1980 were estimated from FY 1971[141] shipments extrapolated to FY 1980 using a 12 percent compounded growth rate.[142] The fraction of radioisotope lost as waste was estimated to be less than one percent for isotopes used in sealed sources, a loss presumed to occur during fabrication of the sources. However, in making promethium sources, waste losses may be as high as 50 percent due to the vapor-deposition technique used. The waste promethium is wiped out of the vapor-deposition chamber with paper or rags which are then handled as solid radioactive waste.

For those isotopes used wholly as tracers and as pharmaceuticals it was assumed that as much as 100 percent may end up in wastes. For tritium, which is used largely in sealed sources but also as a tracer, a 70 percent waste loss was assumed. It was further assumed that all of this waste is sufficiently radioactive to be shipped to a regulated disposal site. The fraction of radioisotope that does not go into waste is presumed to be recycled to source manufacturers, retained by users or lost through decay.

The results of these estimates are summarized in Table 24. All isotopes produced in amounts less than one curie were eliminated from consideration. This table shows that the predominant radioisotopes in the wastes are Co-60, Pm-147, Sr-90, and H-3.

TABLE 24

ESTIMATED RADIOISOTOPE DISPOSAL FROM MISCELLANEOUS PRIVATE SOURCES[a]

Isotope	Domestic[b] Shipments[141] FY 71 (Ci)	Estimated Domestic Shipments[c] FY 80 (Ci)	Estimated Percent of Amount Shipped Which is Lost as Waste	Curies To Waste 1980
Am 241	-	3,212	< 1	< 32
Ce 144	37	103	< 1	< 1
Co 60	3,000,000	8,000,000	< 1	< 80,000
Cs 137	43,400	120,000	< 1	< 1,200
I 131	5.6	15.5	<100	< 15
Ir 192	89	247	< 1	< 3
P 33	1,065	2,953	<100	< 2,900
Pu 238	-	13,022	< 1	< 130
Po 210	997	2,764	< 1	< 28
Pm 147	213,000	590,000	< 50	<295,000
Sr 90	1,200,000	3,300,000	< 1	< 33,000
Ta 182	3,700	10,260	< 1	< 100
H 3	91,700	270,000	< 70	<189,000
			Total in Waste	<601,000

[a] Includes all domestic wastes except those from the nuclear fuel cycle and those from the government.

[b] Isotopes produced in amounts less than 1 curie per year were not included.

[c] A compounded annual growth rate of 12 percent was assumed.

Since no published information was found concerning the volume of radioactive waste classified according to industrial source, only the approximate estimate shown in Table 24 could be made.

It has been estimated that the amount of liquid waste generated per employee at a typical establishment is roughly 2 to 30 cubic meters per year while the solid waste generated per employee is about 0.06 to 0.16 cubic meters per year.[143]

In 1970, the number of people employed by processors and packagers of radioisotopes, by private research laboratories, and by miscellaneous private establishments in the nuclear industry totaled 5,729.[144]

Extrapolating these employment figures (again assuming a 12 percent annual growth) gives an employment estimate of 17,800 for 1980. The estimated volume of waste for 1980 is obtained by multiplying the employment figure by the estimated waste volumes per employee. As a result, in 1980 the volume of liquid waste generated may be from 1.3 to 19 million cubic feet, and the volume of solid may be from 38,000 to 100,000 cubic feet.

Because of the lack of published information on these private waste sources, no reasonable estimate of geographic distribution could be made.

The number of source users will probably be large (estimated on the order of thousands), which may complicate the collection and shipment of waste. However, the total amount of radioactive waste generated in this category is small compared to that generated by the nuclear power industry; therefore the impact upon the disposal site need will not be very great, but allowances must be made for the required transportation systems. It is suggested that the distribution be assumed to be proportional to the population in each geographic area.

RADIOACTIVE WASTES FROM GOVERNMENT SOURCES

The primary sources of government radioactive wastes are the Atomic Energy Commission and the Department of Defense.

Atomic Energy Commission Sources

By far the largest portion of government radioactive wastes are generated by the Atomic Energy Commission as a result of weapons production, research and development at AEC laboratories, and acceptance of wastes from other government agencies and commercial ventures before commercial repositories were established.

Distribution and Types of Wastes

The AEC radioactive wastes are widely distributed over the 26 sites listed in Table 25[145] and are classified by types as shown in Table 26. Each of these sites produces solid wastes and discharges low-level liquid wastes. The high-level liquid wastes (from fuel reprocessing plants) are confined to three sites: Hanford, Washington; Savannah River, South Carolina; and the National Reactor Testing Station in Idaho. "Intermediate-level" liquid wastes (requiring confined storage) are also produced at seven additional sites: Los Alamos, New Mexico; Oak Ridge, Tennessee; Rocky Flats, Colorado; Miamisburg, Ohio; Long Island, New York; Argonne, Illinois; and Columbus, Ohio. Action plans are under study at each of these sites to reduce or eliminate the liquid wastes by converting them to solid wastes and/or shipping them offsite.

Production Rate of Solid and Liquid Wastes

As shown in Table 27, the total volume of solid wastes currently produced is about 1.7 million cubic feet per year. Six million gallons per year of high-level liquid wastes will be generated in 1980, mostly from continued nuclear reactor operation for weapons production at the Savannah River site.

Cumulative Generation of Solid Wastes

In a discussion concerning a transuranium solid waste repository in a salt formation, workers at ORNL estimated the cumulative volume through 1980 of compacted, plutonium-contaminated wastes from AEC facilities[146] to be relocated to a permanent repository to be 3,220,000 cubic feet.

An estimate of the total volume of accumulated solid wastes to be placed in burial grounds at various AEC sites through 1980 is given in Table 28.[146] A total of 1,650 million cubic feet of beta, gamma, and alpha contaminated material is present at four AEC sites. Only 117 million cubic feet of this is plutonium-contaminated, the rest being fission product-contaminated soil. Of this, only 2.8 million cubic feet were considered for relocation to the salt mine repository; the remainder would be left at the four sites which would become *in situ* repositories.

Radionuclide Content of the AEC Wastes

The long-lived fission products usually inventoried in AEC wastes are Sr-90 and Cs-137. Quantities of these two products are usually directly related to the quantities of plutonium

TABLE 25

IDENTIFICATION OF MAJOR AEC SITES PRODUCING RADIOACTIVE WASTES

Site	Designation	Location	Contractors
AMES	Ames Laboratory	Ames, Iowa	Iowa State Univ.
ANL	Argonne National Lab.	Argonne, Ill.	Univ. of Chicago
BET	Bettis Atomic Power Lab.	Pittsburgh, Pa.	Westinghouse
BMI-C	Battelle Memorial Inst.	Columbus, Oh.	Battelle Mem. Inst.
BNL	Brookhaven Nat. Lab.	Upton, N.Y.	Assoc. Univ.
FMPC	Feed Materials Production Center	Fernald, Oh.	National Lead Co. of Ohio
HAN	Hanford Facilities	Richland, Wa.	Several[a]
K-25	Oak Ridge Gaseous Diffusion Plant	Oak Ridge, Tenn.	Union Carbide
LASL	Los Alamos Scientific Laboratory	Los Alamos, N.M.	Univ. of Calif.
LOV	Lovelace Foundation	Albuquerque, N.M.	Lovelace Found.
LRL-B	Lawrence Radiation Lab, Berkeley	Berkeley, Calif.	Univ. of Calif.
LRL-L	Lawrence Radiation Lab, Livermore	Livermore, Calif.	Univ. of Calif.
MOUND	Mound Laboratory	Miamisburg, Oh.	Monsanto Res.
NB	New Brunswick Lab	New Brunswick, N.J.	(AEC)
NRTS	Nat. Reactor Testing	Idaho Falls, Idaho	Several[b]
NTS	Nevada Test Site	Mercury, Nev.	Reynolds Elec. & Eng. Co.
ORNL	Oak Ridge Nat. Lab.	Oak Ridge, Tenn.	Union Carbide
PAD	Paducah Gaseous Diffusion Plant	Paducah, Ky.	Union Carbide
PIN	Pinellas Ordnance Plant	St. Petersburg, Fl.	General Elec. Company

TABLE 25 (Continued)

Site	Designation	Location	Contractors
PORT	Portsmouth Gaseous Diffusion Plant	Piketon, Oh.	Goodyear Atomic Corp.
RF	Rocky Flats Plant	Rocky Flats, Col.	Dow Chemical
SAN	Sandia Laboratories	Albuquerque, N.M.	Sandia Corp.
SNPO	Space Nuclear Propulsion	Jackass Flats, Nev.	Westinghouse
SR	Savannah River Facil.	Aiken, S.C.	E.I. duPont de Nemours & Co.
Y-12	Y-12 Plant	Oak Ridge, Tenn.	Union Carbide

[a] Atlantic Richfield Hanford Company; Douglas United Nuclear; Westinghouse Hanford Company (subsidiary of Westinghouse); Battelle-Northwest (Division of Battelle Memorial Institute).

[b] Argonne National Laboratory; General Electric Company; Idaho Nuclear Corporation; Westinghouse.

TABLE 26

QUALITATIVE INDICES* TO TYPES OF RADIOACTIVE WASTES HANDLED AT AEC SITES

Site	Region	Liquid Wastes			Solid Wastes	
		Low Level	Intermediate Level	High Level	Contains Transuranics	No Transuranics
HAN	Pacific	a	b	c	d	b
SR	South Atlantic	a	b	c	d	b
NRTS	Mountain	a	b	j	d	f
LASL	Mountain	a	b	None	d	b
ORNL	East South Central	a	b,i	None	d	b
FMPC	East North Central	a	None	None	None	b
Y-12	East South Central	a	None	None	None	k
RF	Mountain	a	b	None	None	b
SAN	Mountain	a	None	None	e	g
PANT	West South Central	a	None	None	d	f
NTS	Mountain	a	None	None	d	f
K-25	East South Central	a	None	None	f	f
PAD	East South Central	a	None	None	None	f
PORT	East North Central	a	None	None	None	f
MOUND	East North Central	a	b	None	None	f
BNL	Middle Atlantic	a	b	None	h	h
BMI-C	East North Central	a	b	None	None	h
LRL-B	Pacific	a	None	None	None	h
LRL-L	Pacific	a	None	None	None	h
SNPO	Pacific	a	None	None	None	h
BET	Middle Atlantic	a	None	None	None	h

---

*See next page for key to index numbers and previous table for identification of sites.

TABLE 26 (Continued)

Site	Region	Liquid Wastes			Solid Wastes	
		Low Level	Intermediate Level	High Level	Contains Transuranics	No Transuranics
NB	Middle Atlantic	a	None	None	None	h
AMES	East North Central	a	None	None	None	f,h
PIN	South Atlantic	a	None	None	None	g
LOV	Mountain	a	None	None	h	h

Key to Indices

a. Monitored; treated if necessary; after treatment, effluent released and residue handled as solid waste.

b. Treated by evaporation, precipitation, ion exchange, decay storage, etc.; after treatment, effluent released at or below limits and residue handled as solid waste or high-level "liquid."

c. Concentrated for interim and long-term storage; overheads treated as intermediate- or low-level waste.

d. Buried retrievably on site.

e. Shipped to approved site for retrievable burial.

Key to Indices (continued)

f. Buried on-site.

g. Shipped to AEC site for burial.

h. Shipped to commercial burial ground.

i. Some ILW has been disposed of by hydrofracturing.

j. Treated by fluidized bed calcination and stored as dry, granular solid.

k. Placed in raffinate pits with sludges from low-level liquid treatment.

TABLE 27

QUANTITIES OF RADIOACTIVE WASTES HANDLED PER YEAR AT AEC SITES

Site	High-Level Liquids (million gallons)			Solid Wastes[b]
	Present	Estimated 1977	Estimated 1982	(thousand cu. ft.) Present[c]
HAN[a]	8.0	0.6	0.1	150
SR[a]	5.0	5.0	5.0[e]	370
NRTS[a]	0.6	0.7	0.7	400
LASL	None	None	None	190
ORNL	None	None	None	160
FMPC	None	None	None	30
Y-12	None	None	None	30
RF	None	None	None	220
SAN	None	None	None	<10
PANT	None	None	None	-
NTS	None	None	None	10-20
K-25	None	None	None	<10
PAD	None	None	None	10-20
PORT	None	None	None	<10
MOUND	None	None	None	100
BNL	None	None	None	<10
ANL	None	None	None	30-40
BMI-C	None	None	None	<10
LRL-B	None	None	None	<10
LRL-L	None	None	None	20-30
SNPO	None	None	None	10-20
BET	None	None	None	20-30
NB	None	None	None	<10
AMES	None	None	None	<10
PIN	None	None	None	<10
LOV	None	None	None	10-20
Total	14[f]	6[f]	6[e]	1700[d]

See next page for notes and for identification of sites.

TABLE 27 (continued)

Key to Indices

a. Liquid waste volume figures are primarily based on the rehandling of stored inventories since these mask the smaller volumes from current operations and some of the latter are classified.

b. For this column, "handled" means buried or shipped as indicated in Table 26; excludes solids produced by concentration of high-level liquids.

c. Based on data for 1969, 1970, or 1971.

d. Total burials at AEC sites; excludes quantities shipped to licensed commercial burial grounds.

e. Assumes continued operation of production facilities.

f. Current inventories total about 86 million gallons of liquids, sludges, and wet salt cake.

TABLE 28

ESTIMATED BACKLOG OF SOLID RADIOACTIVE WASTES AT VARIOUS AEC BURIAL GROUNDS

Waste Burial Site	Volume (millions of ft^3)				
	Total Volume Including Beta-Gamma Soil and Waste	Transuranium Waste			
		High Radiation Level Soil and Large Equipment	High Radiation Soil and Waste	Low Radiation Soil and Waste	
				Pre-1971	1971-1974
HAN	1500	3	90	6	0.13[a]
SR	∿ 10	0.1	0.1	0.8	0.12[a]
ORNL	15	1	3	10	0.04[a]
NRTS	∿ 3	<0.1	<0.1	2.25[a]	0.26[a]
TOTAL	1528	4.1	93.2	19.05	.55

[a] It is assumed that these wastes will be relocated to the proposed national radioactive waste repository.

produced for nuclear weapons and the total inventories are classified information. Nearly all of the Sr-90 and Cs-137 are stored in high-level (heat generating) waste tanks mixed with other fission products. The other heat generating fission products have shorter half-lives and decay out during the first 10 years of storage. The fission products which produce significant radiation and heat generation levels (during these first few years of storage) are Ce-144, Ru-106, Ru-103, Zr-95, and Pm-147. In materials contaminated with fission products only the total beta plus gamma radioactivity is reported, and the fission product spectrum depends on the age of the waste, the irradiation time, and the separations that were done during chemical processing. The total quantities of the fission products present in the AEC wastes could be estimated from classified data on the rate of production and accumulated quantities of plutonium over the past 25 years. These inventories would include significant quantities of such long-lived nuclides as C-14, Se-79, Zr-93, Tc-99, Pd-107, Sn-126, I-129, and Cs-135.

The transuranium elements which result from weapons production are usually characterized as "plutonium," and the content is often reported simply as plutonium-239, the most prevalent isotope. The isotopic composition of weapons-grade plutonium is classified information, but "typical" numbers given for mixed AEC and commercial wastes are 1 percent Pu-238, 60 percent Pu-239, 24 percent Pu-240, 11 percent Pu-241, 4 percent Pu-242, along with associated Am-241, Am-243, Cm-242, and Cm-244.[146] Additional long-lived nuclides such as Cm-245, Cm-246, Cm-247, and Bk-247 are also produced by AEC research programs such as the transuranium element program.

The plutonium content of accumulated radioactive wastes at AEC sites is given in Table 29.[147] These quantities are orders of magnitude only. The total is in the range of 1,200 to 2,100 kilograms of plutonium with an additional, classified amount in high-level liquid waste tanks at Hanford and Savannah River. This latter quantity is a small fraction of the total plutonium in accumulated wastes (and can be estimated from fractional waste losses in the reprocessing plants). In one sense the plutonium in these wastes may not be waste at all because it is conceivable that part of the plutonium could be recovered and added to the plutonium stockpile.

Radiation shielding is frequently required for low-level wastes containing fission products. Even when fission products are absent, Am-241 grows into the plutonium from Pu-241 decay; this sometimes makes shielding necessary, depending on the age of the plutonium, its total amount, and the self-shielding characteristics of the waste.

TABLE 29

ESTIMATED PLUTONIUM CONTENT OF ACCUMULATED RADIOACTIVE WASTES AT AEC SITES
(As of End of FY 1972)

Responsibility	Site	Tanks or Bins		Cribs, Ponds, Pits		Burial Grounds		Other		Site Totals
		Kg.	Notes or Ref.	Kg.	Notes or Ref.	Kg.	Notes or Ref.	Kg.	Notes or Ref.	Kg.
AEC	Hanford[b]	A[a]	148	277.5	148	366	149,150	-	-	644 + A
AEC	SRP[c]	B[a]	148	0.094	152,d	24.9	153,154,d	-	-	25 + B
AEC	NRTS	15.1	155,e	Minor	f	398	149,g	-	-	413
AEC	Nev. Test Site	-	-	-	-	0.02	149	100 to 1000	h	100-1000
AEC	Oak Ridge	ca. 7	156	0.634	157	2.675	157,i	-	-	8.3
AEC	LASL	-	-	X	j	4.77	153,k	-	-	4.8
Category Totals		20 + A + B		278		800		100 to 1000		1200-2100 + A + B

TABLE 29 (Continued)

Notes to Table 29

a. Classified; see reference 148.

b. For details, see reference 153.

c. For details, see reference 151.

d. Includes Pu-238.

e. See also reference 149, which indicates 20 kilograms.

f. No data found, but sources such as reference 155 indicate that minor amounts of plutonium may be present in various seepage ponds, dry wells, basin sludges, etc.

g. Includes 37.5 kilograms awaiting burial as of 6/30/72; see also reference 155.

h. Estimate based on reference 159.

i. Reference 154 indicates 6.4 kilograms.

j. Little data are found, but gram to kilogram quantities of plutonium are believed present in old seepage pits. See references 160, 161, 158. Data from reference 161 were used in Table IV of reference 158 to estimate that seven grams of plutonium have carried over into canyon alluvium from old waste disposal facilities and practices; inferentially, a larger quantity remains in pits.

k. See also reference 163 which indicates 4.65 kilograms and reference 154 which indicates six kilograms.

Waste Compositions

Liquid wastes are either aqueous solutions too concentrated to dilute to discharge to the environment or very concentrated salt solutions created by evaporating water and volatile acids to reduce the waste volume.[163] Often the solution is neutralized with caustic to create a less corrosive solution. These salt solutions are usually evaporated to dryness to form a salt cake and treated as solid wastes.

Solid wastes at AEC sites containing a wide variety of chemical compositions can be divided into six approximate categories: 1) cellulose; 2) ash (incinerated cellulose); 3) sludge; 4) salt cake; 5) contaminated equipment; and 6) cladding. The relative volumes of these different types of wastes were not obtained in this study, but cellulose is by far the largest, with high-level wastes being primarily salt cake. Typical compositions[163,164] are given in Table 30.

Detailed Inventory of a Selected AEC Site--Hanford

In order to display the complex interactions involved in radioactive waste management at an AEC site, the Hanford Reservation was selected. The inventory, presented in Appendix P, includes the waste management steps underway at the site and indicates that complete decommissioning of such a site could cost billions of dollars.[165-170]

Department of Defense Sources

Department of Defense radioactive wastes are principally those associated with the Navy's nuclear powered ships. The radioactive wastes from nuclear powered ships and their support facilities are widely distributed among 12 seacoast installations. The total quantities of solid wastes, listed in Table 31[171] average 90,000 cubic feet per year and 1,200 Ci per year, reported as cobalt-60. These solid wastes are shipped to AEC or commercial burial sites. The total quantity of liquid wastes discharged to the environment at these sites was 2,600,000 gallons in 1970, containing 0.024 curies of radioactivity reported as cobalt-60, but including some tritium. The liquid wastes were subsequently diluted to meet discharge requirements. Approximately 1,200,000 gallons of liquids containing 0.8 curies and 150 cubic feet of ion-exchange resin containing 60 curies were discharged at sea at known remote locations during 1970. Projections to 1980 are not available, so it is suggested that 1970 figures be used.

TABLE 30

TYPICAL LOW-LEVEL RADIOACTIVE WASTE DESCRIPTION

WASTE TYPE	CELLULOSE			ASH			SLUDGE			EQUIPMENT			CLADDING			SALT CAKE	
GENERAL DESCRIPTION	CLOTH PAPER PLASTIC WOOD FLOOR SWEEPINGS SOME GLASS SOME METAL SOME CERAMICS			INCINERATED CELLULOSE WASTE INCL. INERTS*			CONCRETE PLASTER OF PARIS VERMICULITE FeOH CHEMICAL SALTS FLOCCULATING AGENTS ION EXCHANGE RESINS			STAINLESS STEEL MILD STEEL LUCITE POLYURETHANE SOME OTHER METALS			STAINLESS STEEL ZIRCALOY			ALKALINE SODIUM SALTS	
TYPICAL CHEMICAL COMPOSITION	CHEMICAL	FORMULA	WT%	CHEMICAL	FORMULA	WT%	CHEMICAL	FORMULA	WT%	CHEMICAL	FORMULA	WT%	CHEMICAL	FORMULA	WT%	CHEMICAL FORMULA	WT%
	CELLULOSE	$(C_6H_{10}O_5)_x$	40	SILICA	SiO_2	35	CALCIUM OXIDE	CaO	15	IRON	Fe	55	IRON	Fe	74	$NaNO_3$	45
	POLYETHYLENE	$(C_2H_4)_x$	15	IRON OXIDE	Fe_2O_3	40	SILICA	SiO_2	50	NICKEL	Ni	10	CHROMIUM	Cr	18	$NaNO_2$	7
	PVC	$(C_2H_3Cl)_x$	15	ALUMINA	Al_2O_3	10	ALUMINA	Al_2O_3	5	CHROMIUM	Cr	5	NICKEL	Ni	8	NaOH	5
	SILICA	SiO_2	6	CALCIUM OXIDE	CaO	10	MAGNESIA	MgO	10	PLEXIGLASS	$(C_5H_4O_2)_x$	10	OR ZIRCONIUM	Zr	100	$NaAlO_2$	20
	IRON	Fe	4	PERCENT VOLATILES		5	IRON OXIDE	Fe_2O_3	20	POLYURETHANE	$(NH_2CO_2C_2H_5)_x$	10				Na_2CO_3	10
	ALUMINUM	Al	1				WATER	H_2O		WATER	H_2O	5				OTHER	3
	CALCIUM OXIDE	CaO	5							ALUMINUM	Al	1				WATER OF HYDRATION	10
	WATER	H_2O	5							ZIRCONIUM	Zr	5					
	NEOPRENE	$(C_4H_5Cl)_x$	10														
SPECIFIC GRAVITY																	
UNCOMPACTED	0.1			0.5			2			0.5			0.5			2.0	
COMPACTED	0.5			0.65			2			2.0			1.5			2.0	
SPECIFIC HEAT (Btu/(lb)(°F)	0.3 (PLASTIC, CELLULOSE)			0.2 (SAND, CLINKER)			0.17 (CONCRETE CLINKER)			0.12 (STEEL)			0.12 (STEEL)			0.2	
THERMAL CONDUCTIVITY (Btu/(hr)(ft²) (°F/ft)	0.035 (CORRUGATED CARDBOARD)			0.041 (WOOD ASH)			0.5 (CONCRETE)			HIGHLY VARIABLE 0.04 - 20			HIGHLY VARIABLE 0.04 - 20			0.15 (DRY)	

TABLE 31

RADIOACTIVE SOLID WASTE FROM U.S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES FOR 1966 THROUGH 1970

Facility	Region	1966-1969 Average/Year Curies	1966-1969 Average/Year Thousand Feet^3	1970 Curies	1970 Thousand Feet^3
Portsmouth, New Hampshire Naval Shipyard	Northeast	22	91	14	16
Groton, New London, Conn. Electric Boat Div., Tender at State Pier, & Sub Base	Northeast	8	365	12	140
Newport News, Virginia Newport News Shipbuilding	South Atlantic	14	276	28	312
Norfolk, Virginia Naval Shipyard and Tender	South Atlantic	6	27	9	146
Charleston, South Carolina Naval Shipyard and Tenders	South Atlantic	13	44	8	6
Pascagoula, Mississippi Ingalls, Nuclear Division	East South Central	<1	<1	0	0
San Diego, California Tenders at Ballast Point	Pacific	1	2	<1	1
Long Beach, California Naval Shipyard and Base	Pacific	<1	<1	<1	<1
Vallejo, California Mare Island Naval Shipyard	Pacific	8	101	12	2
Bremerton, Washington Puget Sound Naval Shipyard	Pacific	10	71	18	1327
Pearl Harbor, Hawaii Naval Shipyard & Sub Base	Pacific	5	3	5	4
TOTALS		169	979	106	1954

[a] This table includes all radioactive waste from tenders and nuclear-powered ships. This radioactivity is primarily cobalt-60.

TRANSPORTATION OF RADIOACTIVE WASTES

The requirements for transportation of all radioactive wastes, whether high- or low-level, are similar, the major difference being the need for heat removal and a greater degree of shielding with high-level wastes. Therefore, transportation treatment for both high-level and low-level radioactive wastes are combined in this study, with emphasis on high-level waste transport.

Regulations for Transportation of Radioactive Wastes

The body of Federal regulations concerned with the general transportation of radioactive materials are those of the Department of Transportation (DOT).[172] In addition, the AEC regulates the packaging and shipping of fissile material and large quantities of radioactive materials.[173] The Federal Aviation Administration, the Coast Guard, the Federal Highway Administration, and the Postal Service have issued special regulations for shipping by air,[174] water,[175] highway,[176] and mail,[177] respectively. The main burden of these regulations falls on the shipper, who is required to furnish a safe package to the channels of transportation. In addition, of course, the carrier is required to make certain provisions for the safe handling and storage of packages and vehicles. An unofficial summary of the DOT regulations, which provides for a general grasp of the subject, has been published recently.[178]

Since about 1968 the Federal regulations have been based on, but are not identical with, the 1967 regulations of the International Atomic Energy Agency (IAEA).[179] The IAEA regulations are directly applicable only to the operations of the Agency. However, in the interest of safe international transportation of radioactive materials, many countries have based their national regulations on those of the IAEA. It may be anticipated that, as the IAEA regulations change to reflect increasing knowledge and experience, so also will those of the United States. Since 1970 the IAEA has been considering proposals for a revision of its 1967 regulations. However, it does not appear that major changes in the United States regulations will result from the IAEA changes.[180] A full discussion of the technical rationale of an earlier version (1964) of the IAEA regulations has been published.[181]

Transportation regulations of the individual States do not normally impinge directly on the transportation of radioactive materials as such. However, the typical highway weight restrictions (35 to 37.5 tons gross weight) have already affected the shipment of irradiated reactor fuel elements and probably will affect future shipments of high-level wastes because economics of the massive shielding requirement forces cask designs as heavy as the transportation system permits.

A review of the classification of radioactive materials and their packaging is given in Appendix Q.[172,173,180,181] Classification into categories depends upon the amount of radioactivity in the shipment. Most low-level wastes fall into category B (0.001 Ci to 20 Ci) of Transport Group I for which packaging must meet requirements under severe accident conditions and DOT approval. All high-level wastes will fall into the "large quantities" category of Transport Group I which requires, in addition, special structural tests and both AEC and DOT approval.

Transportation Safety Requirements

Safety in the transportation of radioactive materials is provided by two main lines of defense. The first objective is to prevent release of material or radiation dose from occurring at all. The second is to reduce the consequences of any accident that does occur by appropriate recovery action or by equipment design.

Attainment of the goal of accident prevention, of course, depends on the actual performance of the people involved. The education and training of shipping department and carrier personnel in the importance of strict adherence to the spirit and letter of the regulations is vital.

An indication of the level of performance of the evolving system of regulations and procedures may be obtained from the following record.[182] In the period 1949-1970, during which there were millions of shipments of radioactive material, 160 cases were reported in which the vehicle was involved in an accident or package damage was suspected. In 26 of those cases radioactive material was released outside the vehicle.

Bases for Transportation System Requirements

The conceptual design of a system to transport radioactive wastes is based on the following criteria:

- All packaging and shipment of radioactive wastes will be in accordance with applicable Federal and State regulations now in effect.
- There should be at least one Federal repository for high-level wastes in the early 1980's. However, by the year 2000, the capacity needs and

expanded shipping needs could well suggest requirements for additional storage sites.

- The modes of transportation of radioactive wastes will be those currently in use, i.e., motor trucks and railroads. While barges are frequently mentioned for the shipment of irradiated reactor fuel, no firm plans now exist for barging wastes from current land-based nuclear reactors.

- The existing commercial disposal sites for low-level wastes (six as of February 1973) licensed by the AEC or agreement States will continue to operate as part of any national disposal system. (Alternately, they could be replaced by nearby sites with different storage designs.) If waste disposal regulations are changed to require temporary storage or retrievability of wastes containing long-lived actinide elements, it is assumed that these sites will upgrade their practices accordingly and that the sites will be modified if necessary to meet other siting criteria. If the sites do not meet such future criteria, they will likely be decommissioned and returned to a status of unrestricted use.

Design of Transportation Systems for Radioactive Wastes--Containers and Protection

Transportation of type A quantities (less than 0.001 curies) of miscellaneous wastes will continue in regulation containers (mostly steel drums) in ordinary freight cars and trucks. Similarly, much of the solid wastes from light water reactors may be shipped in standard steel drums because the concentration of radioactivity is low enough to qualify as LSA (less than 0.1 micro curies per gram).[183] However, the economical shipment of large amounts of radioactive wastes, particularly those generated in the nuclear fuel cycle, requires specially designed containers and vehicles. The AEC publishes a directory of container standards to assist container designers and shippers of radioactive and fissile material.[184]

Following is a review of some of the recent designs for containers for type B quantities of low-level (alpha) wastes.[185] The first is a rail system being used to ship plutonium wastes from Rocky Flats, Colorado, to the National Reactor Test Station in Idaho. A number of 55-gallon drums are loaded inside two standard 8 foot x 8 foot x 20 foot cargo containers, which are in turn loaded inside an AEC owned ATMX-600 series railcar. These are massive, double-walled steel box cars especially designed and constructed to resist the damaging effects of severe rail accidents.

A commercially designed system now in use at Argonne National Laboratory utilizes a 5 foot x 6 foot x 7 foot protective overpack containing wastes in steel boxes. The overpack is a double-walled, rectangular steel box with a six-inch space between the walls filled with shock and thermal insulation to protect the contents against accident or fire.

A similar but much larger system uses a double-walled, insulated accident-resistant box having the 8 foot x 8 foot x 20 foot dimensions of a conventional modular cargo container. It holds a payload of 15 tons (42 standard 55 gallon drums). These latter two systems are evolutionary developments from a 33-inch diameter x 48-inch high, single walled, insulated steel cylinder designed to overpack a single 55 gallon drum.[186] All of these containers were designed to meet the requirements for type B packaging.

From consideration of these recent designs it is probable that the economic solution to the problem of shipping large volumes of low-level wastes involves a reusable overpack container (which may be the vehicle itself) which provides the basic mechanical strength and thermal insulation required by the tests for type B and "large quantity" packaging. This overpack encloses several standard containers, such as drums or boxes, which are the units to be stored or buried at the disposal site. In cases where the level of radioactivity is high enough to require additional shielding the overpack may consist of two or more nesting boxes.[187]

Current plans call for shipment of canisters of solidified high-level wastes by truck or rail from fuel reprocessing sites to a Federal repository.[185] A 30 ton cask designed for truck shipment would contain only three or four canisters while a 100 ton railroad cask could hold up to 36 canisters. These casks will have the same general design as casks used to ship highly radioactive spent fuel. The casks will have a steel inner shell about an inch thick and an outer shell about two inches thick. The outer shell will probably incorporate cooling fins and some form of internal cooling system. Several inches of shielding material, probably of steel or depleted uranium, will be positioned between the two shells. Lead may be used but it is less desirable as shielding material because of its low melting point. A layer of hydrogenous material, such as borated water, is included to provide neutron shielding. The shielding must be sufficient to reduce the radiation dose rates on the surface of the car or vehicle and at six feet from the surface to 200 and 10 millirems per hour, respectively.

It has not yet been determined whether the fuel canisters will be shipped "wet" or "dry", i.e., in water or in air. The current conceptual designs of the repository allow for either possibility.[188] An external blower might be needed to keep the accessible external surface temperature below the DOT regulatory limit of 180°F. The cask and any auxiliary cooling equipment would be nestled in a specially constructed, heavily reinforced rail car.

While the design of high-level waste casks does not require technological breakthroughs, it does present a challenge with respect to heat transfer techniques and material characteristics. The optimum design will require the balancing of several cost factors including those of preshipment storage, transportation, heat removal, and shield material and fabrication.

Methods of Transportation

Practically all radioactive wastes are now and will continue to be shipped by railroad and motor truck. Present plans are to transport most high-level wastes from reprocessing plants to the Federal repository by rail in massive casks.[188] Low-level wastes are shipped by rail and truck packaged in a variety of ways depending on the quantity, form and shielding requirements of the material. The lack of rail service at nearly half the reactors already built and being planned will be an important factor in the transportation picture.[189]

If the concept of off-shore nuclear reactors is accepted, barge shipments of reactor wastes may be necessary. Barges have the advantage of very large weight limits and low freight costs. However, barge shipments are slow and there is usually a need for trans-shipment from/to a land vehicle at one end of the trip. Air shipments of wastes are penalized by weight and bulk factors in addition to safety concerns. However, it should be noted that dirigibles, which would follow courses charted in detail to avoid surface hazards, are seriously being considered as vehicles for transporting large quantities of radioactive wastes.

Distances from Sources to Disposal Sites

The average one-way distances between various types of sources and disposal sites were crudely estimated by use of a scaled map.[189] Distances for the miscellaneous producers and users of radioisotopes were arbitrarily taken to be the same as for the reactors, which are rather widely scattered. The results are shown in Table 32.

TABLE 32

AVERAGE ONE-WAY DISTANCES BETWEEN SOURCES AND DISPOSAL SITES FOR RADIOACTIVE WASTES

Source	Disposal Site	Distance (miles)
Reprocessing Plants	Central U.S. Repository	1,000
Reprocessing Plants	Tennessee Repository	700
Reprocessing Plants	Commercial Burial Sites	100
Fuel Fabricators	Commercial Burial Sites	200
Reactors	Commercial Burial Sites	300
Isotope Producers and Users	Commercial Burial Sites	300

Methods and Equipment for Handling Small Radioactive Waste Accidents and for Decontamination Transport Systems

The stringent containment required by regulations for large quantities of radioactive materials is expected to reduce to an almost negligible level the probability of a large accident in the transportation system. An account of treatment methods for small radioactive waste accidents and for routine transportation equipment decontamination is given in Appendix R.[190-192]

Accountability of Radioactive Waste Materials Associated with Transportation

There are two important types of materials accountability in the transportation of radioactive wastes, both of which are required by Federal regulations. The first is applicable to any radioactive material, while the second is applicable only to fissile material. To insure that radioactive material is delivered only to qualified destinations, AEC regulations require a shipper to determine that the consignee is licensed to receive such material.[193,194] Furthermore, in order to maintain accountability, facilitate the tracing of misrouted shipments, and provide vital information in case of accident, the DOT regulations require the shipper to furnish the carrier with an accurate quantitative description of the contents of radioactive shipments.[172] In addition, large shippers of radioactive materials have found it worthwhile to develop a system of internal documentation based on centralized consignor authority and standardized forms.[195]

To prevent the diversion of fissile materials, special AEC regulations apply to shipments involving more than 5000 grams of such materials.[196] These require that such shipments be in the continuous personal custody of an authorized individual or that the carrier use a system of physical protection and exchange of hand-to-hand receipts at all points of transfer of custody. The regulations applicable to the security of shipments of fissile material have recently been greatly strengthened.[197] While most shipments of radioactive wastes will not be affected by this regulation, large shipments of low-level plutonium wastes and enriched uranium wastes could be affected.

RADIOACTIVE WASTE MANAGEMENT SYSTEM DESIGN

Bases for Radioactive Waste Disposal

The concept of carefully designated and designed disposal sites for radioactive wastes is based on the premise of prevention of uncontrolled leakage into the environment. To achieve this objective, several basic assumptions were made which provided overall guidance for the conceptual design of the sites.

- All radioactive wastes in solid form, except materials from uranium mills and mines or low-level wastes which might be acceptable for other disposal sites, will be received at nationally designated and licensed disposal sites.

- Radioactive wastes will be divided into the two broad categories previously defined, low-level wastes and high-level wastes.

- High-level radioactive wastes received from fuel reprocessing plants will have been stored for an average of five years to reduce the heat generation rate and radiation hazard.

- High-level radioactive wastes will be converted to a dry solid stable form and placed in a sealed container prior to shipment to a designated national repository.

- Low-level radioactive wastes will be converted to a dry solid stable form and placed in a sealed container prior to shipment to a designated disposal site. Liquid and combustible wastes may be received at the site and converted to a dry stable form prior to their disposal or storage.

- Because acceptable concepts for ultimate disposal for radioactive wastes are not yet available, the management concept for high- and low-level radioactive wastes will be that of interim retrievable storage for time periods up to approximately 100 years. It is expected that during this retrievable storage period the long-term hazards of the wastes will have been fully evaluated, and acceptable concepts for disposal or storage will have been developed. At that time, the decision for ultimate disposal could be reevaluated.

- The government (AEC) radioactive wastes will be managed separately by the AEC and will not be included in the national disposal system in this study. It is expected, however, that the philosophy for management of AEC radioactive wastes will be compatible with that of other radioactive wastes.

- The repository will be operational in the early 1980's.

- Environmental safeguards at the national disposal sites will be enforced to assure isolation of the radioactive wastes.

Types and Quantities of Radioactive Wastes

The types and quantities of radioactive wastes have been discussed in detail in a previous section of this chapter, but they are discussed in summary form here as they relate to the design of the national disposal sites.

The rate of heat release from commercial radioactive wastes accumulated through the year 1975 will be about four million watts after five years of storage at fuel reprocessing facilities (in 1980). The amount of high-level and other radioactive wastes generated after 1975 will increase nearly exponentially. For example, the amount of wastes accumulated at fuel reprocessing facilities between 1976 and 1980 will be approximately four times that accumulated through the year 1975.

Government Wastes

A significant quantity of solidified radioactive wastes generated by the AEC is presently confined at AEC sites in interim storage facilities. Because of the special circumstances associated with the packaging and shipment of these solidified wastes to other disposal sites, the AEC plan for the management of these wastes is currently undergoing thorough study of promising potential methods for acceptable on-site long-term storage.[198] Management of AEC wastes within the national system is considered to be beyond the scope of this study, and these wastes are not included in the designs of the national disposal sites. Shipment off-site to a national repository for long-term storage could be undertaken, however, if no on-site alternative can be shown to be safe, acceptable, and economical. A complicating factor for some AEC radioactive wastes which is under study is the treatment and disposal of contaminated soil at the AEC sites.

Solid Wastes

Solid wastes are the most important type of radioactive waste in the concept of a national system. Assuming the high-level solid waste is sealed typically in 12 inch diameter by 10 foot high canisters, approximately 600 to 900 canisters would be available for shipment to a national repository from commercial nuclear fuel reprocessing plants by the end of the year 1980.

Solid low-level wastes are produced at several stages of the commercial nuclear fuel cycle: 1) mining; 2) milling; 3) conversion; 4) enrichment; 5) fuel fabrication; 6) irradiation; and 7) reprocessing. During the year 1980 approximately 2.5 million cubic feet of cellulosic trash (such as paper, cloth, wood, paints, and plastic) contaminated with radioactive material will be produced.[137] The densities of the uncompacted wastes range from about 2 to 200 pounds per cubic feet. About one-half to two-thirds of the wastes, by volume, are combustible and can be reduced in volume by a factor of about 50 and in weight by a factor of about 20 by incineration.[199,200]

About one-half to three-fourths of the wastes, by volume, are compactable and can be reduced in volume by factors of two to ten by compression.

For system design purposes, an overall volume reduction factor of ten was assumed for the above solid low-level wastes after incineration and compression, resulting in approximately 250,000 cubic feet of solid wastes from the trash produced in 1980.

It is expected that about 400,000 cubic feet of noncombustible solids will be generated from solidified liquids, impounded solids arising from water treatment, activated components of nuclear reactors, and cladding hulls, during the year 1980. Assuming the accumulated inventory of solid wastes generated before 1980 is three times that generated during the year 1980, the total volume of the low-level solid waste inventory will be 2.6 million cubic feet by the end of 1980. If these low-level solid wastes are sealed in 4 foot x 6 foot square containers, approximately 20,000 of these containers will have been received at a national disposal site from the commercial nuclear power industry.

Uranium mining and milling tailings are not included in the totals expected at the national disposal site because of the large quantities of material involved (estimated at four million tons per year in 1980).[140] Uranium mill tailings have radioactivity levels of only 2 x 10^{-9} Ci/gm (about two-thirds of that in typical uranium ores). Since most uranium mines are located within 10 miles of a uranium processing mill, it may be possible to impound these insoluble mill tailings by backfilling mined out slopes in underground mines, by refilling open pit mines, or by other in-place fixation techniques.

Liquid Wastes

The types and quantities of liquid radioactive wastes generated by the nuclear power industry merit review since current practices involve dilution and controlled release of very dilute wastes (principally tritium). Since tritium has a 12.3 year half-life, it should not be considered a long-term potential contaminant of man's environment. Current AEC regulations[201] permit release of tritium if the concentration in water is less than 0.1 microcurie per milliliter. During the year 1980, it is estimated that the amount of tritium released to surface water at commercial nuclear reactor sites will be 0.8 million curies.[137] About a thousand curies of other isotopes will be released to the surface waters in 1980 in dilute streams meeting the AEC regulations.

Liquid plutonium-containing wastes or other liquid wastes containing long-lived radioisotopes should not be released to surface waters above acceptable concentrations. These wastes can be "fixed" as solids in a variety of ways. Some current practice includes mixing with concrete or absorption onto solids such as fuller's earth or diatomaceous earth and packaging into containers for disposal as solids.[139] The quantities of these materials have been included in the solid waste stream.

It is estimated that by 1980 1.3 to 19 million cubic feet of low-level liquid wastes will be generated each year by miscellaneous private sources.

A current inventory[202] of the Morehead, Kentucky, commercial burial site reveals that the liquid wastes received averaged 34,000 gallons per year (4,500 cubic feet per year) from 1964 to 1970 with no perceptible increase during this period. In 1971 the liquid waste receipts suddenly increased to 340,000 gallons per year, probably as a result of reactor operators' shifting to a near "zero release" philosophy. With the assumptions that (a) the receipts from reactors would increase at the same rate as the nuclear power economy (from 8.1 $GW_{(e)}$ in 1971 to 150 $GW_{(e)}$ in 1980) and (b) that the Morehead site currently represents about 50 percent of the liquid waste receipts by commercial low-level burial sites in the United States, the projected liquid wastes received by all burial sites from nuclear reactors would be 1.4×10^6 cubic feet per year by 1980.

The receipts from nonreactor sources, assuming a growth rate of 12 percent per year, would be 25,000 cubic feet per year in 1980. This is only 0.13 to 1.9 percent of the amount of waste estimated to be generated by these nonreactor sources. One interpretation of the discrepancy could be that 98 to 99.9 percent of the generated liquid wastes are currently being diluted and flushed down the sewer. If essentially all of this liquid were to be shipped to the disposal site (which will be the trend in the future), the total reactor-plus-nonreactor liquid wastes would be 2.5 million to 20.2 million cubic feet per year.

As the retention of radionuclides at the source improves, the fraction of low-level liquid wastes shipped to the disposal site is likely to increase significantly unless volume reduction facilities are installed at the sources. For the purposes of estimating the size of a national disposal facility, an arbitrary receipt of 2.5 million cubic feet per year of nonnuclear power liquid wastes is assumed in 1980. This corresponds to a total of 4 million cubic feet per year (30 million gallons per year) received in total in 1980. The total accumulated receipts through 1980 are taken to be 16 million cubic feet (1.2×10^8 gallons).

Gaseous Waste

Radioactive gaseous wastes from the commercial nuclear power industry are comprised primarily of noble gas fission products. Some gaseous activation products are also produced in nuclear reactors. These gaseous fission products can leak or diffuse into the primary coolant of a nuclear reactor, from which they are vented. Except for krypton-85 and tritium (which have half-lives of 10.7 years and 12.3 years, respectively) these radionuclides have relatively short half-lives, so that they decay rapidly to nontoxic levels. Gaseous wastes are treated by condensing any vapors, permitting radionuclides to decay during a holdup period, and then releasing airborne wastes through high efficiency filters. Current AEC regulations[203] permit release of gaseous wastes after sufficient dilution in air. These gaseous wastes are usually released from a stack at least 100 feet tall to achieve atmospheric dispersion. During the year 1980 approximately 4.7×10^7 curies of gaseous wastes are projected to be released to the atmosphere from the commercial nuclear power industry.[137]

High-Level Radioactive Waste--Strategy of Disposal

Policies of the U.S. Atomic Energy Commission currently emphasize retrievable surface storage in the near term for the management of high-level radioactive wastes.[203]

In the early 1980's, and until a permanent disposal concept has been accepted and implemented, an operable Federal repository may be established for the storage of solidified and packaged high-level wastes for a period of 100 years.[133] The AEC thus has deferred commitment to permanent disposal of radioactive wastes for a period up to 100 years, during which time continued research and development on the concepts for permanent disposal might produce significant improvements.

The retrievable surface storage concept (the facility is currently named the Retrievable Surface Storage Facility, or RSSF) of a Federal repository for solidified and packaged commercial high-level waste has been demonstrated to be safe, although public acceptance has not yet been ascertained. The Retrievable Surface Storage Facility is visualized in this study as a group of concrete modular structures, above or just below ground level, serviced by a single receiving and transfer facility. One of the concepts studied by the AEC is a water-cooled storage module design in which high-level waste containers would be stored in water-filled basins. Air-cooled systems are also being evaluated.

An option available to commercial fuel reprocessors is the storage of high-level wastes at the chemical processing plant as a liquid for as long as five years to permit decay of short-lived radioisotopes before the waste must be solidified. The wastes must be transferred from the fuel reprocessing sites to the Federal repository no later than ten years following reprocessing of the irradiated fuel. During the initial liquid storage period the heat generation rate and radiation hazard of the waste is reduced, as shown in Figure 26, before it must be solidified for shipment and long-term storage.[204] The waste would then be converted to a solid form (which is presently not well defined but could be a calcine, rocklike, or glassy form) suitable for transport and storage. The latter two forms generally have low solubility and leachability in water to further immobilize the radioactive products and are therefore generally preferred. These two forms also have a high thermal conductivity which appears to provide an economic advantage. The higher thermal conductivity permits solidification of the high-level waste with a minimum of interim liquid storage, thus avoiding a large investment in liquid storage tanks and associated facilities, or it permits the use of canisters of larger diameter for older waste. A typical high-level waste canister of solidified waste is shown in Figure 27.

The canisters of solidified high-level wastes will be shipped by rail or truck in casks which will provide cooling and radiation shielding in transit. The shipping casks should meet the requirements of the Department of Transportation[205] for survival after severe tests without the release of radioactive material. The maximum heat generation rate in each canister of high-level waste has been tentatively set at five kilowatts of heat when shipped to the RSSF, but this heat limit is currently being reviewed. This heat generation limit was established to be compatible with expected limitations of the proposed pilot plant repository in bedded salt geologic formations. Because the rate of heat generation for each canister will steadily decrease with

FIGURE 26

HEAT GENERATION RATE OF HIGH-LEVEL RADIOACTIVE WASTES FROM A TYPICAL LIGHT WATER REACTOR AS A FUNCTION OF TIME AFTER DISCHARGE

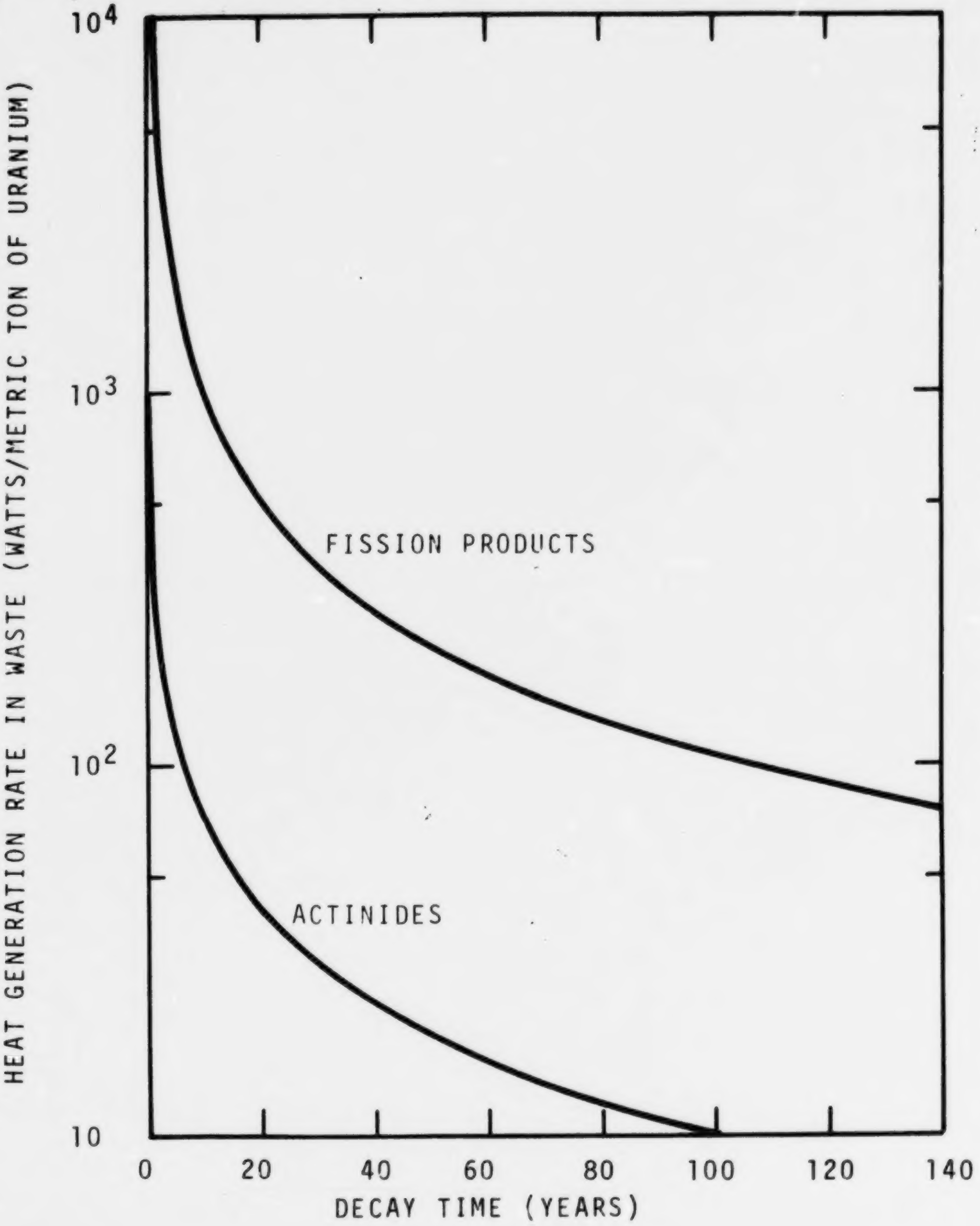
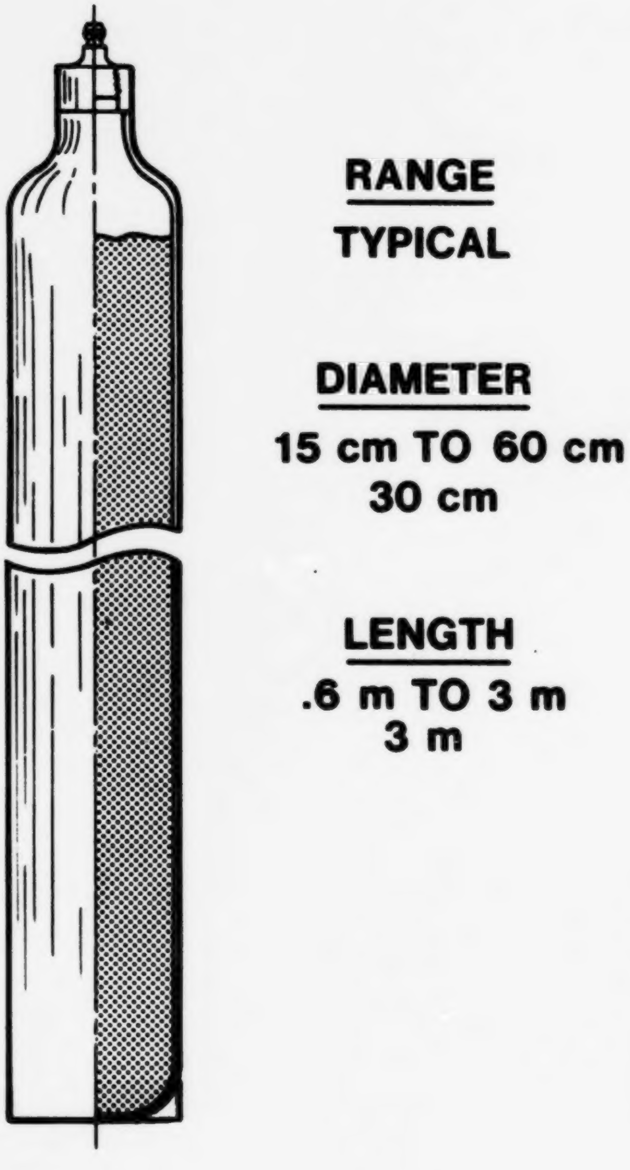


FIGURE 27

TYPICAL CANISTER FOR HIGH-LEVEL
RADIOACTIVE WASTE


RANGE
TYPICAL
DIAMETER
15 cm TO 60 cm
30 cm
LENGTH
.6 m TO 3 m
3 m

time as the radioactive products decay, a higher heat limit for the RSSF could still be compatible with the five kilowatts value for a salt mine.

Upon receipt of the waste at a repository, the Federal Government will assume permanent custody of the high-level radioactive wastes. Current AEC regulations require that the commercial nuclear fuel reprocessor pay the Federal Government a one-time charge, which together with interest on the unexpended balance would be sufficient to defray all costs of retrievable surface storage, disposal, and surveillance.[204]

Potential of Partitioning High-Level Radioactive Wastes

As previously indicated, the hazard and handling problems for nuclear waste are grossly affected by age, volume, physical and chemical characteristics and content of fission and reactor (actinide) products. It would appear that suitable fractionation or partitioning of wastes to portions having different heat generation rates, specific activity, biological hazard decay rates, etc. might result in simpler and safer waste management schemes. Certain waste constituents might be partitioned for later transmutation to innocuous materials in special, high flux nuclear reactors.

In recognition of this possibility, the AEC has authorized work on waste partitioning studies with Atlantic Richfield Hanford Company, Oak Ridge National Laboratories and the Pacific Northwest Laboratories of Battelle-Northwest.[138,204,206,207]

Criteria and General Description for Retrievable High-Level Radioactive Waste Repository

The basic criterion used in evaluating proposed methods for the treatment and storage of high-level radioactive wastes is that no method should permit the release of biologically significant amounts of radioactivity into the environment. Other important criteria for a radioactive waste disposal system are taken from preliminary AEC-supported studies on retrievable surface storage systems for high-level wastes.[208]

Review of the concepts for high-level radioactive waste management indicates that the system should have the following characteristics:

- capability to accept sealed canisters of high-level radioactive wastes which have been previously solidified before transportation to the Federal repository to a form which is chemically, thermally, and radiolytically stable;

- assurance of the health and safety of the public and the protection of the environment;

- safety of operation, including the ability to remove heat and maintain canister integrity and retrievability following extended periods of time;

- controllability of effluent emissions at least to those in 10 CFR 20, and possibly approaching those in proposed Appendix I to 10 CFR 50 for nuclear reactors, which are generally 1.0 percent to 0.001 percent of those now in 10 CFR 20;

- retrievability under all conditions;

- ability to withstand all credible natural forces;

- reasonable capital investment consistent with the objectives of safe waste storage for 100 years or more, and safe recovery from unplanned events;

- modular construction to provide waste storage space on a schedule consistent with future commercial reprocessing waste deliveries;

- contamination-free operations; and

- minimization of operational activities at the storage facility. The shippers should conduct all special operations necessary to meet strict acceptance criteria.

Until a concept for ultimate disposal of high-level radioactive wastes becomes available, it is planned that the Retrievable Surface Storage Facility (RSSF) will be used to store radioactive wastes. A functional diagram of the RSSF is illustrated in Figure 28.

The RSSF's primary requirement is to provide safe storage for encapsulated solidified high-level waste for at least 100 years and to make it possible to retrieve failed or weak canisters from storage areas and repackage the contained waste for continued storage or for shipment.

In the preliminary concept of the RSSF described here,[208,209,210] the waste will be stored in water basins built in modules. A conceptual layout of the water basin is illustrated in Figure 29. New modules will be constructed as they are required to

FIGURE 28

ACTIVITIES IN A RETRIEVABLE SURFACE STORAGE FACILITY
FOR HIGH-LEVEL RADIOACTIVE WASTE

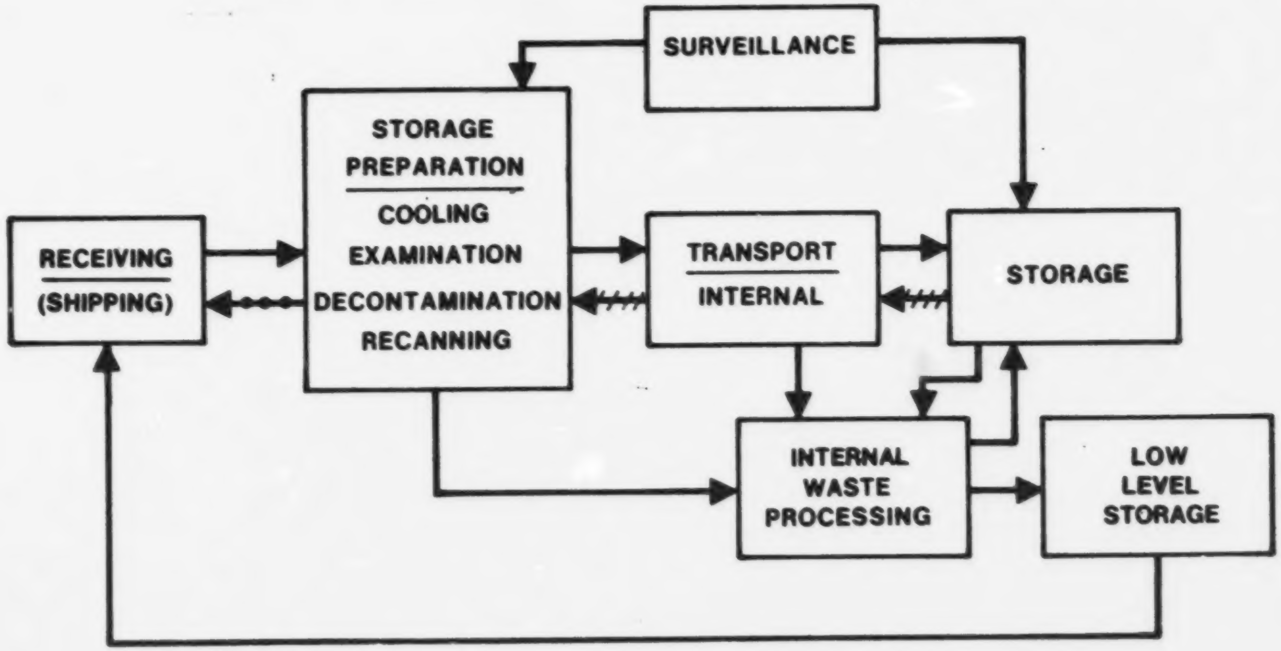
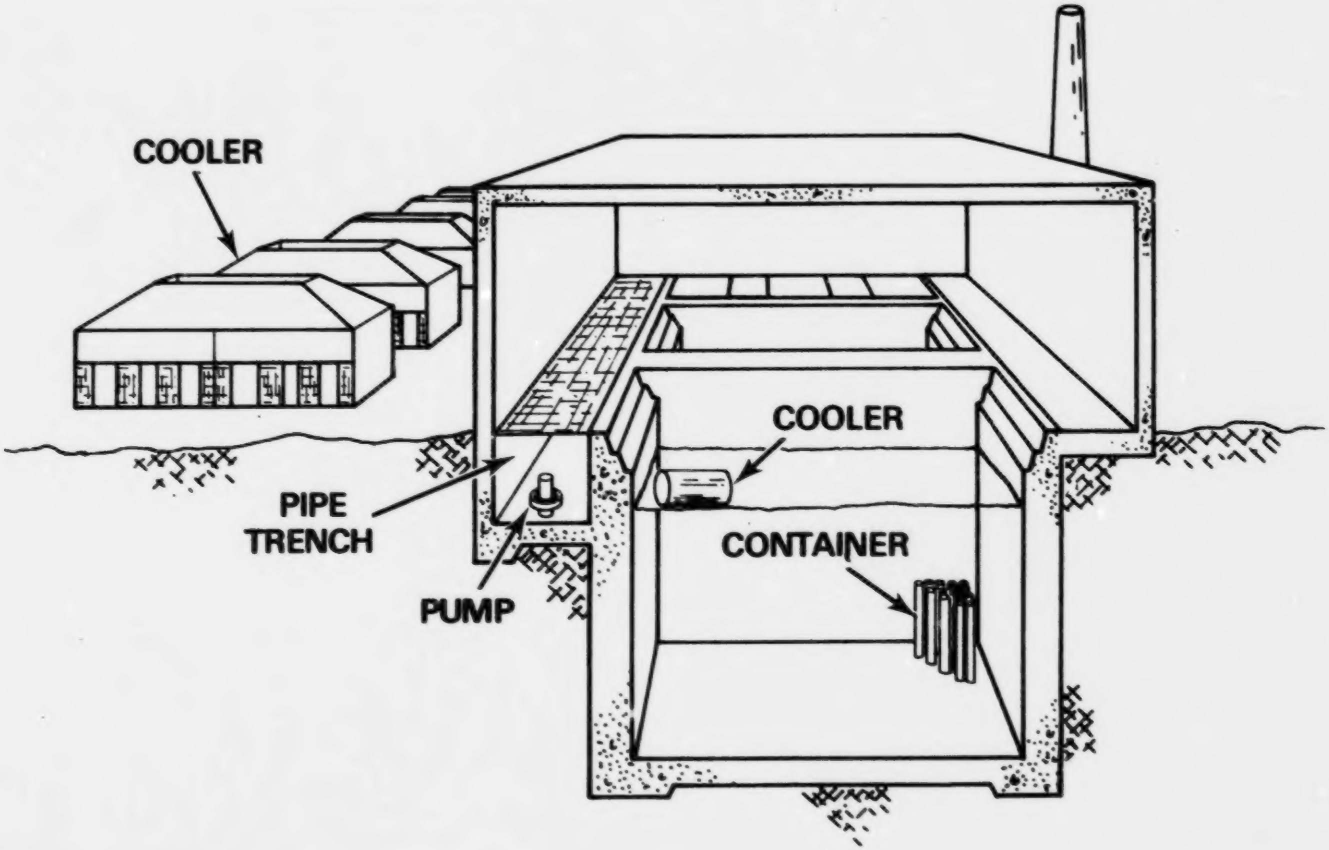

SURVEILLANCE
STORAGE
PREPARATION
COOLING
EXAMINATION
DECONTAMINATION
RECANNING
RECEIVING
(SHIPPING)
TRANSPORT
INTERNAL
STORAGE
INTERNAL
WASTE
PROCESSING
LOW
LEVEL
STORAGE

FIGURE 29

WATER BASIN CONCEPT FOR RETRIEVABLE SURFACE STORAGE FACILITY FOR HIGH-LEVEL RADIOACTIVE WASTES


COOLER
COOLER
PIPE TRENCH
CONTAINER
PUMP

handle the increasing waste inventory. The water in the basins provides shielding and cooling for the canister. Surveillance will be necessary to assure that the canisters remain in satisfactory condition. Extensive monitoring will be used to detect any evidence of canister overheating, leakage or deterioration so that necessary corrective action can be taken if the need arises. In this way, the isolation of the radioactive wastes will be assured.[138]

Storage buildings will be designed for a service life-time of at least 100 years and built to withstand all natural forces which might be expected at the facility such as severe storms, earthquakes, and floods, as well as all credible adverse accident conditions. It is expected that even with nominal maintenance the structures can be maintained in serviceable condition well beyond the design lifetime. The facility will be designed in accordance with nationally accepted codes and standards. A quality assurance program will be applied to the design, fabrication, construction, and testing of structures, systems and components of the facility, to assure that each component of the facility will perform its required function.

In addition to the storage basin, the RSSF also will have facilities to receive, inspect, and decontaminate high-level waste canisters and their transportation casks and repackage failed canisters. Transportation casks containing canisters will be brought into the receiving area within the building where the casks will be removed from the railroad car or truck and immersed in a stainless steel-lined receiving basin filled with water. The canisters will then be removed from the cask and inspected under water before they are moved into the storage basin.

Suggested acceptance criteria for high-level radioactive wastes, based upon preliminary AEC studies,[211,212] are 1) maximum heat per container, 5 kilowatts; 2) canister diameter, 6 inches to 24 inches; 3) overall length, 2 to 10 feet; 4) maximum weight, 8,000 pounds; 5) canister life, 100 years; and 6) waste in a stable solid form.

The use of retrievable surface storage facilities assures that there is a safe solution to the high-level waste problem for 100 years and possibly several centuries. During the time afforded by this action the AEC intends to continue development of an integrated high-level waste management program to provide for optimal ultimate disposal.

Description of Retrievable Surface Storage Facility for High-Level Radioactive Waste

The first stage in construction of the Retrievable Surface Storage Facility will include six to eight concrete-walled water basin modules, the preliminary design of which[209] is shown in Figure 30. Each module is capable of storing about 500 high-level waste containers. The modules are lined with stainless steel and filled with water before high-level waste containers are emplaced for storage. The height of water above the top of the canisters is sufficient to protect operating personnel from radiation. Above the modules is an enclosed working area from which an overhead crane is used to handle canisters and the optional cover blocks for each module.

Each storage module will be connected to a water-filled transfer aisle by a swing-type door which is opened to allow passage of a waste canister. This door will normally be closed to isolate the water in the module from other modules in the facility if a leaking container should release contamination. One canister at a time is moved under water from the receiving basin through the stainless steel lined transfer aisle to the storage basin. Contaminated canisters are repackaged and/or decontaminated as required before being placed in the storage basin.

The storage basin will be monitored extensively to detect and locate overheating or leaking containers. Radiation detection equipment installed in the recirculating water line of each storage module will provide an early warning of contamination buildup in the facility. Leaking canisters will be removed from the storage module and transferred to the repackaging cell for repair. The contaminated water in the module and transfer aisles will be pumped to the liquid waste disposal system and the storage module and transfer aisles will be decontaminated by flushing with fresh demineralized water. After completion of decontamination, fresh demineralized water will replace the original water.

One central ion-exchange loop consisting of a filter, cooler, ion-exchanger, and auxiliary equipment to filter and clean the water in the modules by removing extraneous chemical ions will treat the storage basin water in all modules. The temperature of the water in each module will be maintained at 120°F by circulation through a heat exchanger. The process flow diagram for high-level waste storage in a water basin is illustrated in Figure 31. A closed loop cooling system consisting of a 5,000 gallon storage tank, two 1,700 gallon per minute pumps and an evaporative cooler will remove heat from the storage basin water.

FIGURE 30

LAYOUT OF WATER STORAGE BASIN FOR RETRIEVABLE SURFACE STORAGE FACILITY FOR HIGH-LEVEL RADIOACTIVE WASTES

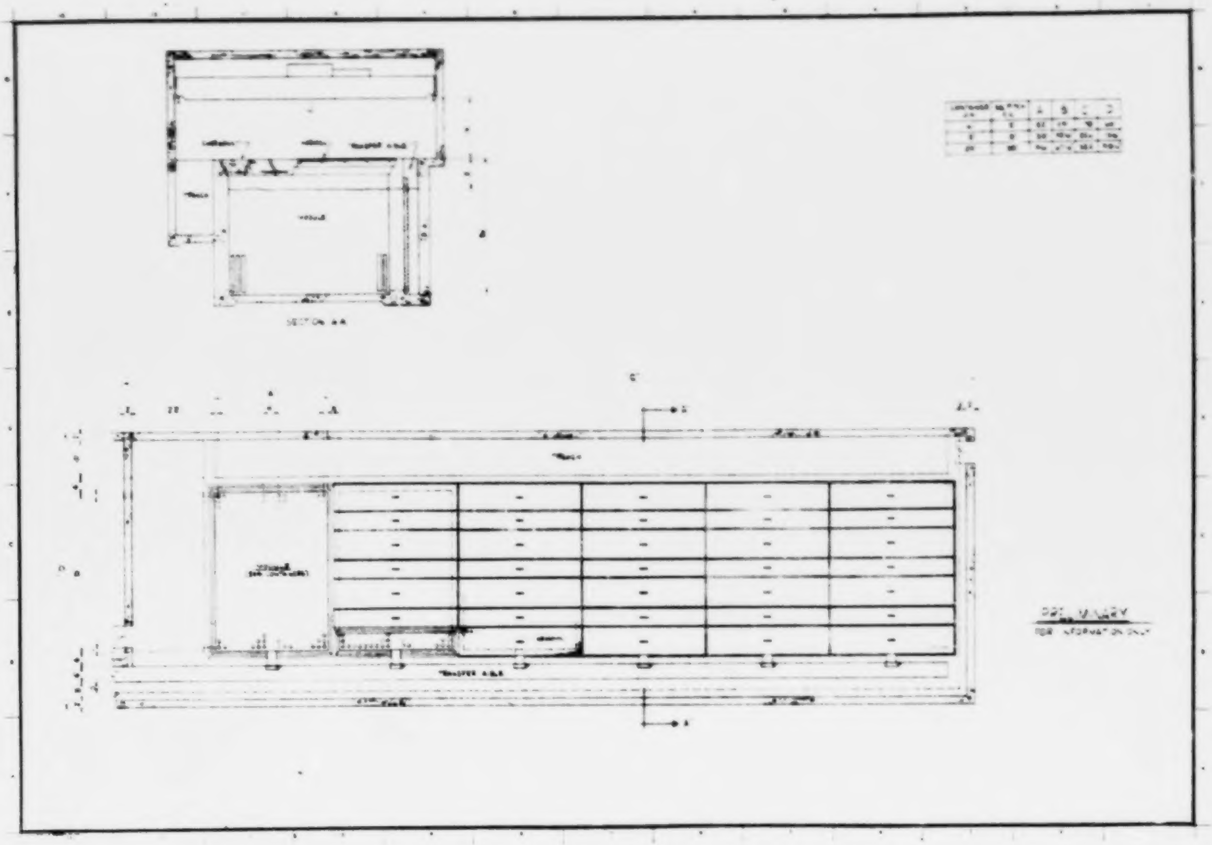
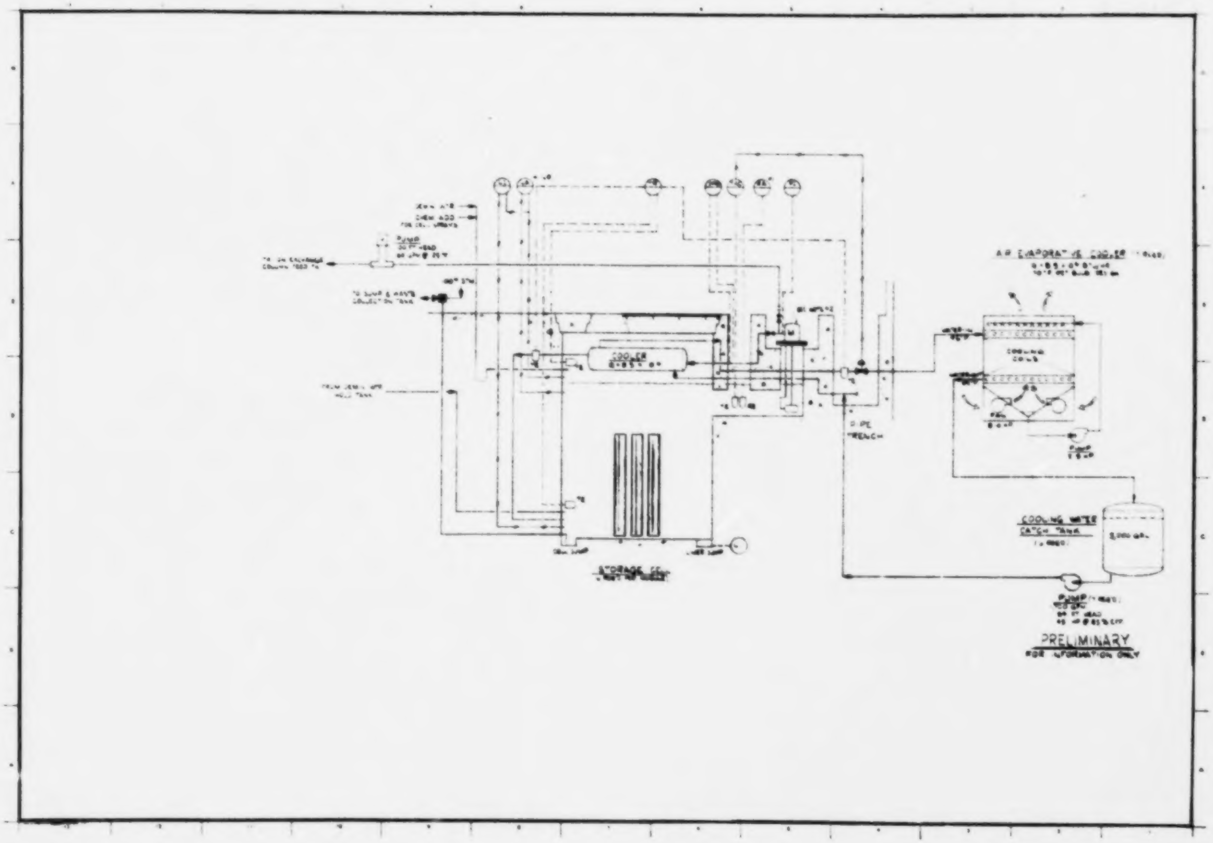


FIGURE 31

BASIN WATER PROCESS FLOW DIAGRAM FOR RETRIEVABLE SURFACE STORAGE FACILITY FOR HIGH-LEVEL RADIOACTIVE WASTE


AIR EVAPORATIVE COOLER
COOLING COILS
PUMP
COOLING WATER CATCH TANK
PUMP
PIPE TRENCH
COOLER
STORAGE CELL
CHEM ADD
PUMP
PRELIMINARY
FOR INFORMATION ONLY

The water in the storage basins will provide a large heat sink, permitting shutdown of the cooling system for preventive maintenance and minimizing the effect of power failures or equipment breakdowns. The water temperature will rise from 120°F after the cooling system is shut down and will reach the boiling point in about two days.[210] Restoration of normal cooling within a day will lower the temperature of the water in the storage basins and return the system to normal operating conditions. In the very unlikely event that normal cooling is not restored within two days, the water will boil and its level will drop a fraction of an inch per hour.[210] The water vapor evolved will be discharged to the atmosphere. Water from either normal or emergency supplies will be added to maintain the water level in the basins until normal cooling is restored. The ventilation filters, which will become plugged with water vapor, will be replaced before the system is returned to normal operating conditions.

Unit Operations for Storage of High-Level Radioactive Wastes

The principal unit operations in the RSSF are receiving and handling, repackaging, and decontamination. These are described in detail in Appendix S.[209]

Potential Retrievable Surface Storage of High-Level Radioactive Waste by the Sealed Storage Cask Concept

An alternative concept for retrievable surface storage of high-level radioactive waste using cooling by natural air convection has been proposed and is currently being evaluated.[188] Although this concept was not selected as a primary basis in this study, it is presented here for information and for consideration in later studies, pending its evaluation by the AEC. This concept, designated the Sealed Storage Cask Concept (SSCC), appears to conform to requirements for self-regulating storage for time periods of hundreds of years.

In this concept, canisters of solidified waste are stored in individual heavy-walled cast steel casks. The casks would be stored out-of-doors to allow natural convection of air around the casks for cooling. Concrete saddles will elevate the casks above the ground to reduce the rate of corrosion from the contact with the soil. No backup or emergency cooling systems are required. Assuming only radiant heat transfer between a waste canister producing five kilowatts of heat and the internal wall of the cask, the surface temperature of the canister would be approximately 550°F and the external temperature of the cask would be approximately 275°F. Internal convection is expected to lower these temperatures appreciably, probably to below 200°F.

A cask sized to accept a waste canister 12 inches in diameter and 10 feet long would have external dimensions of 45 inches diameter and 152 inches length and weigh approximately 35 tons.[213] The canister, which would produce 5 kilowatts of heat, would have steel walls 16 inches thick to reduce the exterior gamma dose rate. The cask design uses an end shielding plug which would be welded to the cask body with a deep penetration weld after the waste container was inserted. A sketch of a cask positioned on support saddles in the field is shown in Figure . Recent studies indicate cooling would be augmented by a vertical orientation.

The Sealed Storage Cask Concept requires special attention to the problem of neutron exposure. Spontaneous fission of actinide nuclei in high-level radioactive waste could produce a significant neutron dose rate at the surface of the cask.[214] The most active neutron producer in the waste is curium-244, which decays with an 18 year half-life. Although the neutron dose rate from the waste after 100 years of storage would be reduced to acceptable levels at the surface of the cask, restriction of personnel access to the storage area would be required during the first few decades of storage. Such restrictions are common and mandatory in many nuclear activities.

Preliminary economic analysis of this concept indicates that capital and operating costs may be less than a water basin storage system.[215] Since the preliminary analysis of the concept has not identified any technical or hazard reasons to disqualify it from the safety viewpoint, the concept is being developed further in parallel with the water basin and other storage systems.

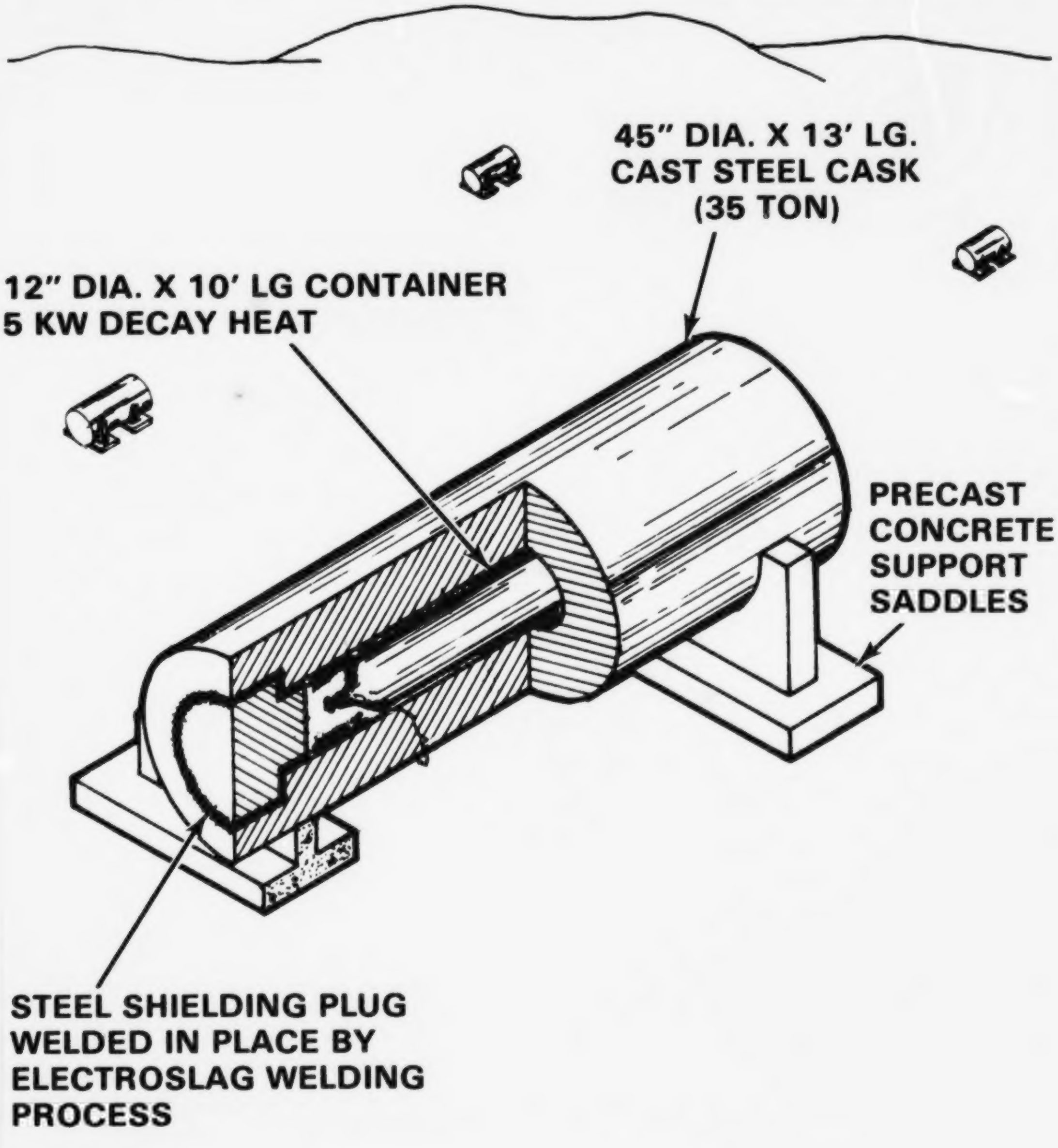
Costs for High-Level Radioactive Waste Repository

Preliminary cost estimates have been made for the high-level waste repository to provide an initial economic appraisal of the conceptual design. The facility would be constructed in stages to handle wastes from a growing nuclear economy. By the early 1980s the first stage of construction would be completed and the facility would be in operation. This first stage includes the receiving and handling facilities and storage modules capable of storing a total of 3,000 waste containers. Since a construction schedule has not been established, all costs were estimated in 1973 dollars with no allowance for escalation.

The capital costs of the high-level waste facility were derived from preliminary estimates by the Atlantic Richfield Hanford Company for the AEC and are shown in detail only to give an example of the cost components. More recent estimates with reasonable variations of the cost parameters indicate capital

FIGURE 32

SEALED STORAGE CASK CONCEPT FOR RETRIEVABLE SURFACE STORAGE OF HIGH-LEVEL RADIOACTIVE WASTE


45" DIA. X 13' LG.
CAST STEEL CASK
(35 TON)
12" DIA. X 10' LG CONTAINER
5 KW DECAY HEAT
PRECAST
CONCRETE
SUPPORT
SADDLES
STEEL SHIELDING PLUG
WELDED IN PLACE BY
ELECTROSLAG WELDING
PROCESS

NOTE: VERTICAL ORIENTATION MAY ALSO BE USED.

costs in the range of $20 million to $40 million. The size of the repository, the quantities of concrete and structural steel required, the quantity of mechanical and electrical equipment necessary to provide safe cooling, the amount of stainless steel required to line the water basins, the quantity and type of equipment needed for handling and repackaging waste containers, process controls, auxiliary equipment, electrical wiring, plumbing, and surveillance instrumentation were considered in the estimates.

A preliminary estimate of the total initial capital cost of the facility is about $37 million. The first stage of construction includes the receiving and handling facilities sized to service subsequent storage modules. Direct and indirect costs associated with the buildings, equipment, and auxiliaries for the receiving and storage facilities amount to $18.5 million,[209,210] as shown in the preliminary estimates listed in Table 33. An allowance of 75 percent of the direct and indirect costs, amounting to $14 million, was estimated for the design of the facility, engineering, quality assurance, and contingencies.[208] Additional storage modules would be constructed approximately every five years to meet projected storage requirements.

Due to the remote possibility of an accidental release of a significant quantity of radioactive material to the atmosphere an exclusion area will be required around the plant. The amount of land which must be acquired for this exclusion area is determined primarily by the exclusion distance, assumed to be one mile.[209] This would require a site property approximately two miles square, or about 2,500 acres. Assuming the cost of land at $1,000 per acre, the acquisition of land is $2.5 million of the capital cost. Access roads on the plant site for trucks and rail cars add another $2 million of the total capital cost, which depends on the existing transportation facilities at the selected site. Off-site transportation systems costs are not included in the estimate.

Costs for operation of the RSSF for high-level radioactive wastes are $3 million and result primarily from operating manpower, utilities, materials consumption, and equipment replacement. The detailed basis used in estimating the operating costs are given in Appendix S.

Transportation Costs for High-Level Radioactive Wastes

Existing commercial railroad and motor truck equipment and facilities will be used to transport radioactive wastes to a repository. A typical high-level waste canister, 12 inches in diameter by 10 feet long, could be transported in a 30 ton cask by either truck or rail. Such a cask could be shipped 1,000

TABLE 33

PRELIMINARY ESTIMATE OF TOTAL COST FOR HIGH-LEVEL RADIOACTIVE WASTE RETRIEVABLE SURFACE STORAGE FACILITY

CAPITAL COST	Direct and Indirect[208] Capital Cost
Receiving Facility:	
Building	\$ 3.7 million
Equipment	\$ 4.0 million
Storage Facility:	
Building	\$ 2.9 million
Equipment	\$ 5.8 million
Auxiliaries:	
Utility Supply and Auxiliary Equipment	\$ 1.5 million
Site Preparation	\$ 0.2 million
Paving and Landscaping	\$ 0.4 million
Total Direct and Indirect Capital Cost of Plant	\$18.5 million
Facility Design, Engineering,[208] Quality Assurance Fee, and Contingencies (75% of Direct and Indirect Capital Cost)	\$14.0 million
Land Acquisition Cost	\$ 2.5 million
Access Roads for Truck and Rail	\$ 2.0 million
Total Capital Cost	\$37.0 million
ANNUAL OPERATING COST (See Appendix S)	
Operating Manpower	\$ 1.4 million
Materials and Services	\$ 1.0 million
Other Operating Costs	\$ 0.6 million
Total Annual Operating Costs	\$ 3.0 million

miles by truck for about $1,500 (in 1972 dollars).[216] Rail freight costs are about the same as truck freight costs up to 1,000 miles one-way, but the round-trip shipping time is nearly doubled. Rail shipment becomes more economically attractive beyond 1,000 miles if shipping time is not a major consideration.

A significant number of shipments of high-level wastes will be taking place in the early 1980s and hundreds of shipments will be required annually by the year 2000. Casks containing arrays of three or more waste canisters weighing between 70 and 100 tons will become economically attractive when enough shipments are made to keep them in use. Because of their weight, these casks could only be shipped by rail. However, payload-to-gross-weight ratio of these large casks is improved by a factor of 2 to 3 over casks with single canisters,[211] and shipping costs per canister would be reduced correspondingly. Handling costs are estimated at $1,000 per shipment plus $80 per waste canister. Freight costs are based on a rate of $50 per ton for carload shipments (minimum weight approximately 20 tons).[216]

The design for a high-level waste shipping cask should show compliance with the safety requirements of regulatory agencies[212] and minimize the total shipping cost. The purchase costs of casks were estimated at $2, $3, and $9 per pound for iron, lead and depleted uranium gamma shielding, respectively.[211] Lead shielded casks weigh about 20 percent less than those with iron shielding, but have a 20 percent higher capital cost.

For single canister casks shipped by truck, the use of lead shielding may minimize total shipping cost because the round-trip time is short and hundreds of shipments could be made in such a cask during its useful lifetime. The capital cost for one of these casks, which would weigh about 25 tons, is estimated to be $225,000.

A large cask shipped by rail car containing six high-level waste canisters would probably use steel shielding because its round-trip time would be fairly long and its useful lifetime only about 100 shipments. An estimate of the capital cost of this cask, which would weigh about 90 tons, is $360,000.

By the early 1980s approximately 900 high-level waste canisters will have been shipped to the Federal repository. Assuming the average one-way shipping distance to be 1,000 miles, if one-third of the waste is shipped in single-canister casks, the shipping and handling cost for transporting this waste to the repository and returning the casks to the fuel reprocessors is approximately $2.6 million (in 1972 dollars, with no allowance for escalation). These shipments could probably also be made with a total of six single-canister casks and three six-canister casks, involving a total capital cost of about $2.4 million.

LOW-LEVEL RADIOACTIVE WASTES

Low-level radioactive wastes may exist in gaseous, liquid, and solid forms. Most liquid wastes are treated at the point of origin to reduce volumes with the provision that effluents have levels acceptable for release to the environment. The concentrated radioactivity is then converted to a solid form which can be handled in the same way as other low-level solid wastes.

This study deals with wastes with radioactivity levels too high for on-site burial, therefore requiring transportation to low-level repositories.

It is believed that low-level wastes (as defined in this report) containing significant content of long-lived radionuclides should be stored in Federal repositories. These wastes can present long-term hazards equivalent to high-level wastes but will not present the short-term problem of removal of large quantities of heat. Thus larger volumes of waste can be stored in a unit volume of repository and a greater freedom is allowed in the storage configuration. However containment (short- and long-term) requirements approximately equal those for high-level wastes.

The conceptual design presented for the LRSSF is developed here from one of several alternatives suggested as possibilities in a preliminary study of an alpha waste interim storage facility made for the AEC.[217,163] Other studies, such as the ongoing LASL study,[218] are not yet sufficiently developed to be the basis of a conceptual design.

The LRSSF consists of a semi-remote receiving and handling area, an evaporator for custom volume reduction of liquid wastes, an incinerator for volume reduction and a high integrity interim storage warehouse.

The volume reduction at the disposal site would vary greatly with the solids content of the feed liquid. Although volume reductions of 50 are commonly attained with cellulosic wastes, much of the feed material would not be combustible and could be sorted to bypass the incinerator; therefore, a relatively conservative overall volume reduction factor of ten for solids is used for design of the incinerator. A volume reduction factor of ten was also assumed for design of the evaporator to convert liquids to solids.

The maximum feed to the processing facility during the year 1980 was established in previous sections to be 2.5×10^6 cubic feet of solids and 3×10^7 gallons of liquid. For design purposes a solids production rate in 1980 of 700,000 cubic feet per year by the processing facility was assumed. The accumulation of low-level radioactive waste through the year 1980 will be 10^6 cubic feet of incinerator ash (resulting from 10^7 cubic feet of combustible solids) and 1.6×10^6 cubic feet of other wastes, or 20,000 of the 4 foot x 6 foot x 6 foot standard waste storage canisters.

A series of five warehouses with a total of approximately 250,000 square feet of floor space (including aisles, etc.) would be adequate through 1980 with the containers stacked three high. It is estimated that 40 percent of this area requires shielding and 60 percent does not. Future requirements beyond 1980 could be met by expansion. This facility should remain intact with assured retrievability for at least 100 years during which time requirements and technology for ultimate long-term disposal could be developed.

Strategy for Disposal of Low-Level Radioactive Wastes

The current storage/disposal method for low-level wastes is direct burial in trenches which are then covered with soil. Commercial burial sites (and contractors at AEC sites before 1970) have placed all solid wastes, including those with a high cellulose content, directly in the ground and then backfilled with soil. In some instances liquid wastes have been converted to a "solid" by mixing with paper, concrete or diatomaceous earth and then directly buried. Generally speaking, there has been little discrimination between low-level wastes with a predominance of fission product contamination and those with actinide contamination.

In view of the long-term toxicity associated with most low-level wastes (specifically, those containing actinide radionuclides) it is believed that the current AEC practice of 20 year storage (rather than disposal) should be extended to commercial sites. Consideration should also be given to extending the retrievable storage period to 100 years. The goal should be a retrievable storage period necessary for development of "ultimate" disposal technology.

Preliminary estimates for several high integrity low-level waste storage concepts in an AEC-supported study were in the range of \$3 to \$5 per cubic foot,[217] compared to a cost of about \$1 per cubic foot (plus transportation) in the current commercial practice of direct burial.[219] Because of the potential for contamination spread in the event of a fire, it may be advisable to render all combustible low-level waste material incombustible before storage. Prior destruction of combustibles has the advantage of significant volume and storage cost reduction. Similar reasoning is applicable to concentration/solidification of liquids.

Inevitably, there will be a host of users of radioisotopes without adequate volume reduction and/or solidification facilities. Thus the retrievable surface storage facility for low-level wastes (LRSSF) should include such capabilities in order to perform custom processing. Fees for the service could be based on the initial volume of waste, the final solids content of the "ashes", the corrosiveness of the chemicals present, and the radioactivity level in the solid or liquid waste.

An AEC task force[220] studied the costs of existing and proposed facilities for reduction of solid wastes by incineration. Their results (Table 34) show that an elaborate offgas treatment system is required for incineration, the capital costs are relatively independent of throughput rate, and operating costs per unit throughput are a strong function of rate. Sources of small outputs may be unable to afford an incinerator, and it may be economically desirable to consolidate compaction from large sources unless transportation costs for the wastes are high. Other waste volume reduction techniques which are in earlier stages of development are discussed in Appendix T.

The early focal point for a disposal site for commercial low-level wastes centered on storage in bedded salt. Storage of low-level radioactive wastes is already being practiced by West Germany in a salt mine at Asse.[221] No preferred concept for ultimate disposal of low-level wastes exists. Preliminary concepts for interim retrievable surface storage facilities for these wastes were investigated briefly by the Atlantic Richfield Hanford Company (ARHCO) for the AEC in a study reported in June 1972.[132] The major concepts suggested by ARHCO were 1) single-level surface vaults with personnel access or warehouses strengthened to withstand tornadoes and earthquakes, 2) multi-level vaults, 3) "canyon"-type concrete vaults without personnel access to failed containers, 4) silos for bulk storage of incinerator ash, 5) an "artificial mountain" honeycombed with vaults that might be converted into a permanent repository, and 6) direct burial of 55 gallon drums in concrete-lined and covered V trenches. Clearly, all of these concepts provide retrievable surface storage.

Currently, design bases for storage of at least the transuranic portion of the low-level wastes are being defined for the AEC by the Los Alamos Scientific Laboratory. The tasks in this program are defined as 1) Characterization of Alpha Wastes,

TABLE 34

INCINERATOR COSTS AT LOW-LEVEL RADIOACTIVE WASTE STORAGE FACILITY FOR 1980 THROUGHPUT

Fraction of Solid Waste Processes at Storage Facility	Maximum Throughput (pounds per hour)	Capital Costs	Operating Costs ($ per cubic foot)
0.1	143	$1.4 million	6.0
0.2	285	1.5 million	3.8
0.5	712	1.7 million	2.3
1.0	1430	2.0 million	2.0

2) Characterization of Environments, 3) Hazards and Consequences Evaluation, 4) Proposed Criteria for Alpha Wastes, and 5) Optimization of Form Environment. Early work is directed toward waste storage problems associated with thermal and radiolytic waste degradation, chemical characterization of wastes, methods for screening stations and monitoring of large volumes of solid wastes, and preliminary radiological considerations and package integrity during the first 20 years of retrievable storage.[218]

A further consideration outside the scope of current high- and low-level waste management involves oversized contaminated process equipment. This waste could be stored as is, the originator could be required to reduce its bulk, or the national disposal facility could contain sawing and mechanical compaction equipment. With the large size and weight penalties for packaging and shipping of solid radioactive wastes, any reduction to the standard maximum package size should be done before receipt at the disposal site.

In the context of this report, the national disposal site will consist of a processing facility and a storage facility. The terminology "national disposal site" for low-level radioactive wastes is at variance with the usual terminology, "storage site", used in the nuclear industry for burial grounds or repositories for low-level wastes.

Criteria and General Description for Retrievable Low-Level Radioactive Waste Storage System

The overall criteria used for the conceptual design of the treatment and storage of low-level radioactive wastes in this report are derived from those previously cited for high-level wastes. The basic premise is that the system should not permit the release of biologically significant amounts of radioactivity into the environment.

The system for storage of low-level radioactive wastes was designed to meet the following requirements:

- it should accept sealed canisters of chemically, thermally, and radiolytically stable, solid low-level radioactive wastes;

- for those low-level wastes which were not converted to an acceptable form prior to receipt at the disposal site, it should provide conversion services for additional fees. These services consist of sorting, handling, volume reduction of combustible solid wastes, evaporation-solidification of liquid wastes, and encapsulation of wastes which require treatment;

- it should provide instantaneous processing capacity at the rate of waste production in 1980 for a plant operating at an efficiency of 80 percent (24 hr/day, 7 day/week operation);
- the health and safety of the public and the protection of the environment should be assured;
- storage capacity for all treated and packaged low-level radioactive wastes accumulated between 1973 and 1980 should be provided;
- operation should be safe and should include the ability to maintain canister integrity and retrievability after extended periods of time;
- effluent emissions should be controlled at least to those in 10 CFR 20, and may be required to approach those in proposed Appendix I to 10 CFR 50[106,138] for nuclear reactors, which are generally 1.0 percent to 0.001 percent of those now in CFR 20;
- the stored wastes should be retrievable under all conditions;
- the facility should be able to withstand all credible natural forces;
- reasonable capital investment should be made consistent with the objectives of safe waste storage with retrievability for 100 years or more and safe recovery from planned events;
- construction should be modular to provide space on a schedule consistent with future waste deliveries;
- contamination-free operation should be provided; and
- operations at the disposal site should be minimized when the burden of special operations necessary to meet strict acceptance criteria can reasonably be conducted by the shippers.

Until a concept for permanent disposal* of low-level radioactive wastes becomes available, a retrievable surface storage facility should be used to store low-level radioactive wastes. It is assumed in this study that only one such facility will be required by 1980.

Other design considerations, such as surveillance, design lifetime, and integrity should be similar to those for high-level wastes.

The use of man-made retrievable surface storage facilities assures that there is a safe solution to the low-level waste problem for many tens of years and possibly several centuries. During this period development of an integrated waste management program should be completed to provide for optimal ultimate disposal.

Description of Retrievable Surface Storage Facility for Low-Level Radioactive Wastes

The concept selected for disposal of low-level radioactive wastes consists of a processing facility for volume reduction plus a facility for storage of the packaged residue for up to 100 years. A flow diagram for the operations in the facility is shown in Figure 33.

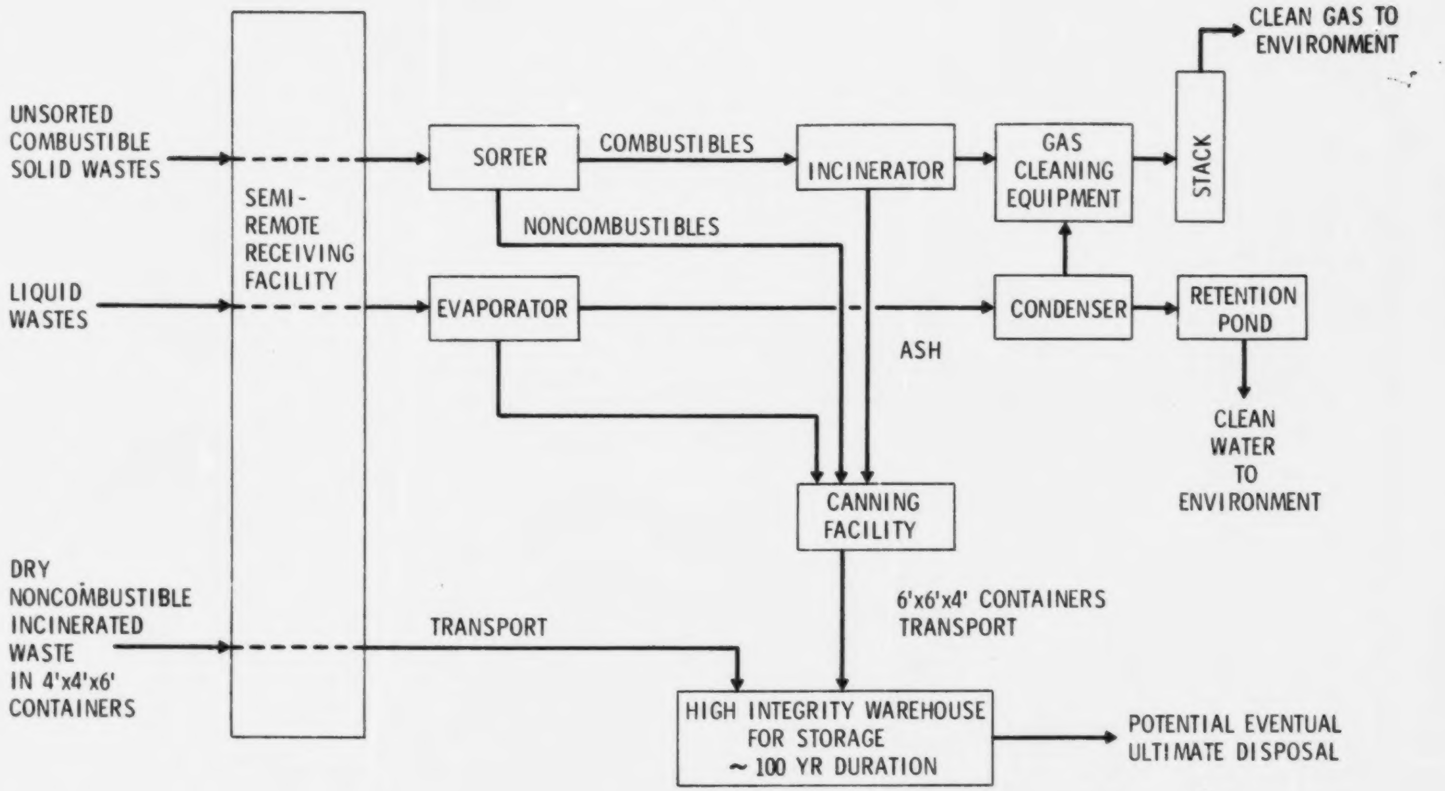
The head-end materials-handling portion of the facility will provide systems for receiving and storage of liquid and solid wastes, segregation of solid wastes into combustible and non-combustible fractions, and decontamination facilities for transportation, materials handling, and process equipment. Material will flow from the head-end materials handling facility to the processing systems or storage. The facility will be capable of handling radioactive materials shipped by rail or truck in bulk or package condition. The receiving section will have access to the decontamination facility so that transportation equipment can be decontaminated as required. The receiving facility will be housed in the processing building to assure that all radioactive materials are contained during transfer operations.

---

*Permanent disposal of low-level radioactive wastes may require confinement for hundreds of thousands of years. A practical technique for accomplishing this is not yet available.

FIGURE 33

LOW-LEVEL RADIOACTIVE WASTE PROCESSING AND STORAGE FACILITY


UNSORTED COMBUSTIBLE SOLID WASTES
LIQUID WASTES
DRY NONCOMBUSTIBLE INCINERATED WASTE IN 4'x4'x6' CONTAINERS
SEMI-REMOTE RECEIVING FACILITY
SORTER
COMBUSTIBLES
NONCOMBUSTIBLES
EVAPORATOR
TRANSPORT
INCINERATOR
ASH
CANNING FACILITY
6'x6'x4' CONTAINERS TRANSPORT
HIGH INTEGRITY WAREHOUSE FOR STORAGE ~ 100 YR DURATION
POTENTIAL EVENTUAL ULTIMATE DISPOSAL
GAS CLEANING EQUIPMENT
CONDENSER
STACK
CLEAN GAS TO ENVIRONMENT
RETENTION POND
CLEAN WATER TO ENVIRONMENT

Sufficient storage will be provided for one week's production capacity of both liquid and solid wastes prior to processing or final placement for storage. Several storage tanks will be provided so that the liquids can be segregated, neutralized, mixed with other wastes, and prepared as fuel for the evaporation or incineration processes. Multiple glove boxes equipped with sorting equipment will allow segregation of the solid waste into noncombustible fractions for transfer to storage or to the packing area for final packaging prior to storage. Feed preparation of combustibles for incineration will also be performed in glove boxes. The decontamination facility to be located in the head-end materials handling and processing facility will be designed to handle the transportation equipment as well as equipment used in the processing facility.

Both combustible liquids and solids will be fed into a remotely controlled incinerator in a shielded area or into an alternative processing scheme for oxidation and volume reduction. Due to the present state-of-the-art, incineration was selected. Use of controlled air incineration to minimize the generation of fly ash and to provide complete oxidation of the offgases is anticipated. The offgases will be routed through a gas cleaning system to assure that the releases are within standards. The same off-gas cleaning equipment will be used to process noncondensible gas from the evaporation and condenser system. The gas cleaning system will consist of wet and dry mist elimination systems, a wet scrubber, and a final stage of High Efficiency Particulate (HEPA) filters. Solids from the incinerator and the gas cleaning systems will be transferred to the solids processing system for final packaging.

Noncombustible liquids will be processed through a remotely operated evaporator located in a shielded area. Special modifications of evaporation equipment may have to be designed to handle these radioactive liquids. Solids from the evaporation step will be transferred to the solids processing system for final packaging. Overheads from the evaporation system will be condensed to remove condensables and noncondensables will be routed through the gas cleaning system for particulate removal before discharge to the atmosphere. Condensate and all other process water will be routed to a retention basin for chemical and radioactive analysis before final discharge. Wastewaters that do not meet effluent standards will be recycled through the evaporation system.

The solids processing systems will be designed to handle all noncombustible solid wastes capable of fitting into the standard 4 foot x 6 foot x 6 foot high metal canisters. The facility will not be capable of processing large pieces of equipment for disposal (as previously discussed, these will have been reduced in size and packaged at their sources) but it will include packaging and compaction equipment. It is anticipated that the final canister will have a welded closure to assure long-term containment. A decontamination section is provided to allow for final decontamination of the waste canisters as part of the final packaging facility. The packaging operation will be performed in glove boxes to control contamination.

The processing systems will be housed in a building with two or three ventilation zones to assure that air is always flowing from the zones of lower-level contamination to the zones of higher-level contamination. Building ventilation will be a major design consideration for this facility since personnel and the environment must be protected from the escape of contamination. All processing and operations must be done in enclosed hood-type facilities, detailed design of which must be carried out with extreme care to assure confinement of radioactive contamination. All waste products (solid and liquid) generated within the facility, primarily from decontamination operations, are processed internally and handled as waste received from outside sources.

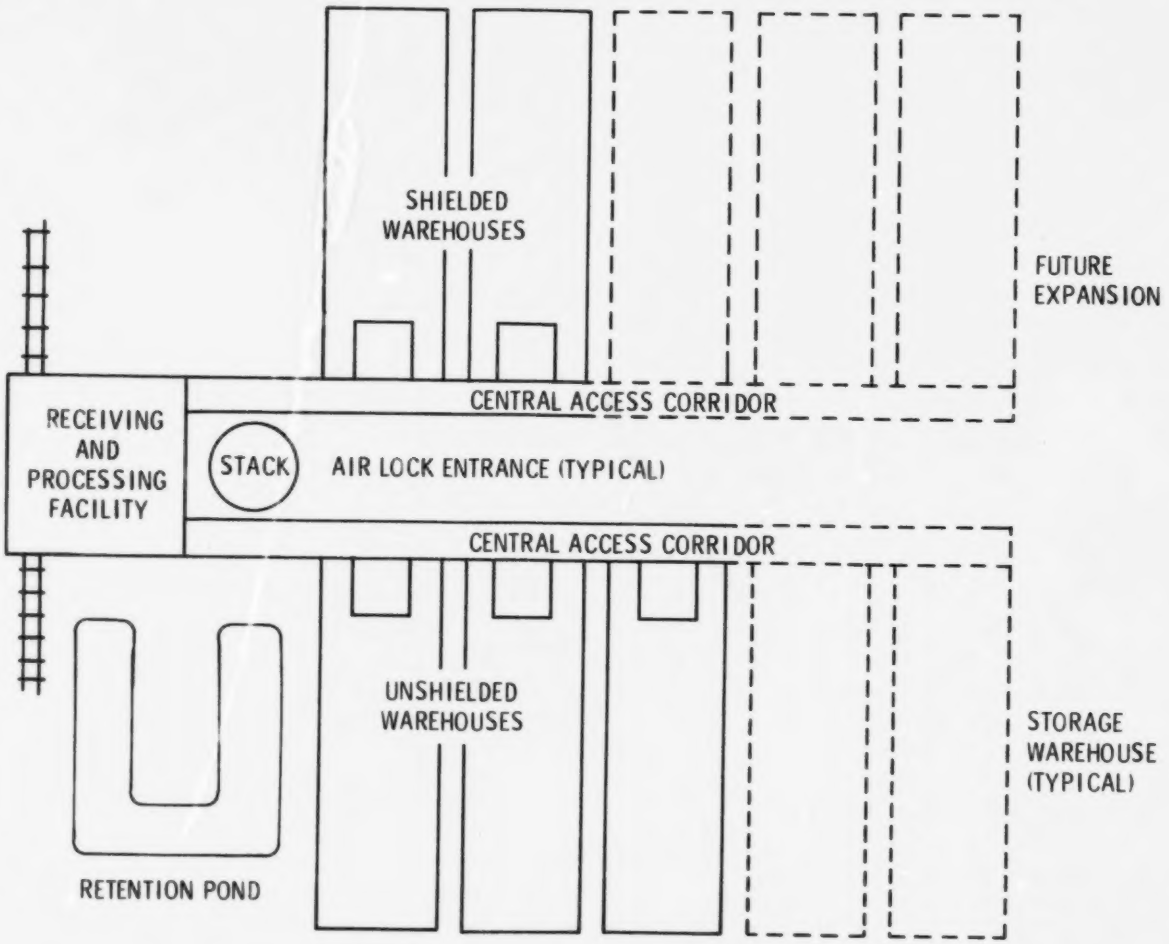
The receiving, handling and processing facility will be connected to two central corridors which in turn connect with the several warehouse structures. For 1980 a total of five warehouses, each 100 feet wide by 500 feet long, will be arranged side by side and will connect at right angles to the central corridors. Each warehouse can accommodate 4,000 waste containers in layers three high. Future expansion of the storage facility will be achieved by building additional warehouses and extending the central corridors. The overall layout is shown in Figure 34.

Two types of warehouses are used, one of which will be for wastes requiring shielding (up to about three feet of ordinary concrete). Waste canisters which require shielding are transferred by remotely operated crane down through the access corridor to the entrance of the appropriate warehouse. There the waste canister is transferred to the remotely-operated warehouse crane for transfer through the air lock and into its storage position. Wastes which do not require shielding are transported by forklift.

Each warehouse is provided with its independent supply of treated and prefiltered ventilation air. The compartmented ventilation exhaust from each warehouse is separately filtered and monitored prior to joining the exhaust air from the remaining warehouses. This compartmentation facilitates identification of canisters which have developed leaks during storage. All exhaust air from each warehouse is combined and passed through a bank of high efficiency filters and is monitored before being exhausted through the central facility stack.

FIGURE 34

OVERALL LAYOUT OF LOW-LEVEL RADIOACTIVE WASTE STORAGE FACILITY


SHIELDED WAREHOUSES
FUTURE EXPANSION
RECEIVING AND PROCESSING FACILITY
CENTRAL ACCESS CORRIDOR
STACK
AIR LOCK ENTRANCE (TYPICAL)
CENTRAL ACCESS CORRIDOR
UNSHIELDED WAREHOUSES
STORAGE WAREHOUSE (TYPICAL)
RETENTION POND

Unit Operations for Storage of Low-Level Radioactive Waste

Unit operation at the disposal site for low-level radioactive wastes will involve 1) receiving, sorting, and handling; 2) decontamination of transportation devices, work areas, and equipment; 3) concentration, conversion to solid, and canning (e.g., incineration of solid wastes and evaporation of liquid wastes); and 4) storage for an extended period.

These operations are discussed in detail in Appendix T.[108,222-226]

Environmental Safeguards at the Repository Site for Low-Level Radioactive Waste

A detailed survey of the geology of the site with regard to groundwater flow and aquifer characterization, structural and long-term stability characteristics of the underlying strata, and tectonic stability and frequency of earthquakes will be required before the plant is located.

Prevailing meteorological conditions (wind velocity and direction versus time, air "dilution" factors, precipitation) and background radioactivity should be monitored and well established before site selection and during site operation. Because of the long storage time anticipated, population trends should be anticipated and the existence of the storage facility should be considered in long-range local and regional plans. Arid regions of low population density with deep water tables are generally preferred but are not essential. It is assumed that an exclusion distance of at least one mile around the activities within the site, or especially from the ventilation stack location, would allow for good atmospheric dilution.

Safety Provisions

Provision for improbable but possible spills and accidents in the receiving area will be identical to those which must occur during transportation (discussed in Appendix Q). Unloading will be done within an enclosed area with well controlled ventilation to prevent direct release of contamination to the environment which might result from surface contamination of containers or rupture of containers during handling. Isolation of spills and cleanup following routine radioactive decontamination procedures[192] will be effected. High radiation levels in wastes will be contained by special shielding. All other material with low radiation doses will be treated in hoods or glove boxes in the same way plutonium is handled in nuclear fuel plants. Direct monitoring of personnel for radioactive contamination and indirect monitoring of radiation doses with badges, pencils, and rings will be conducted. Because of the definition of low-level wastes, no significant heat generation problem is anticipated.

Evaporator operation results in the entrainment of some radioactive aerosols, which are controlled with close-coupled offgas equipment, and is by far the process step with the most potential for contamination spread by incidents such as temperature and pressure excursions. Combustion of organic liquids and cellulose in materials could result in temperature excursions and possible explosions if operating conditions become abnormal. Design for automatic pressure relief (to another enclosed vent system) and equipment shutdown would be an integral part of equipment design, particularly in view of the potential hazard of the radioactivity in the processed material. Release of radioactivity outside of the processing facility would be avoided by backup ventilation decontaminating (filter) systems in case the primary offgas treatments fail. Spills resulting from the canning operation would be handled with routine isolation and cleanup procedures. Sampling of the retention pond should prevent aqueous releases. Environmental surveillance should include the placement of nearby wells for sampling purposes.

Safety problems associated with the storage facility are 1) can rupture followed by contamination spread, 2) criticality, 3) overheating, and 4) natural disasters. Can rupture will be detected by ventilation gas sampling, followed by isolation and removal procedures. Criticality potential detection equipment will be located in the storage array. Similarly, temperature recording will detect unusual radioactive heating. These will be supplemented with automatic fire alarms and automatic fire fighting equipment. Fire should be avoidable in the storage areas because combustible wastes will have been previously incinerated. The facility will be constructed to survive tornadoes and earthquakes and located to avoid floods and ground subsidence. Procedures to prevent sabotage or theft are not yet well developed beyond the usual military-type guard system, a factor which must be considered in detail during the final design phase. In any event, a high, unclimbable fence will surround the total property of the disposal site, and another fence should probably be installed around the processing and warehouse area. The total site should have appropriate audio/visual surveillance.

Accountability and Monitoring

A major problem in handling low-level radioactive wastes is the determination of the amount of radioactivity in the incoming wastes. Waste producers will be required to inventory radioactivity in the wastes they send in terms of curies or grams of fissile materials and curies or grams of other radioactive materials.

The incoming wastes must be monitored for total radiation level, external contamination and the total fissile content (to determine the potential for achieving criticality). It should not be necessary to reopen cans already adequately treated and packaged for storage. The initial monitoring will result in segregation on the basis of radiation level, the need for container decontamination, and the need for treatment. Normal radiation monitoring and isolation techniques should be used in the sorting area with the assumption that all materials contain plutonium.

All effluents of the volume reduction processes will be monitored (stack gases, retention pond effluent) before release. Because of the possibility of accidental releases during processing, environmental monitoring of air, water, land, and biota and people around the site should be conducted continually or routinely.

The solid waste materials should be monitored before canning to provide an estimate of the content of specific nuclides. This will require some sampling. It is hoped that the technology for low-level continuous inventorying of solids will be developed to perform this task, but such technology is not available at this time. A more feasible alternative would be to do "whole body" monitoring of the can after sealing. Improvements in current technology would also be needed for this operation. A check for consistency would then be made between an accumulation of measured can contents and the estimates at the source, with a best estimate being assigned forever to the can contents. Inventory controls would be imposed to decrease the likelihood of creating a critical mass during storage and to segregate temporarily high radiation field materials until decay.

A continuous program of air sampling and can monitoring is needed to check for failed cans.

Once the wastes are safely canned and stored in the warehouses, accountability of radioactive materials is largely a matter of restricting unauthorized access to the facility, keeping adequate records of inventories placed in storage, properly labeling each can for identification, and periodically estimating real-time and projected inventories of radionuclides that build up and decay as time progresses. This last item seriously complicates the inventory record problem, but it is desirable to help define the current and future potential hazard of the waste and to provide input data for decisions that might be necessary regarding future disposition of the waste. Duplicate records should be kept in permanent, offsite storage centers so that future generations can have access to them.

Costs for Low-Level Radioactive Waste Disposal Site

The capital and operating costs for facilities with incineration capacities of up to 500 pounds per hour have been estimated, but no data on actual operating or capital costs for facilities of the size required to meet the total production rate in 1980 were available.[220] Therefore, a capital and operating cost estimate was made for a facility that could concentrate an average of 3,500 gallons of liquid radioactive waste and incinerate an average of 1,400 pounds of solid radioactive waste per hour (these are average hourly production values comparable to the annual rates previously described). The capital and operating costs of remote radioactive processing facilities are highly dependent on the design criteria and operational procedures established for the facility. The details of these high-spot estimates are presented in Appendix U.

Capital Costs

The estimated capital cost for the processing facility is rounded to $20 million, as shown in Table 35. The high-spot capital cost for the storage facility is $24 million, also shown in Table 35.

The storage warehouse will occupy a space of about five acres. The processing facility will be smaller, about 0.5 acres. To provide added protection for the public, a controlled plant area will be needed around the plant and warehouse. A one mile exclusion distance should be adequate for low-level wastes. This would require a site property of about 2,500 acres. Assuming the cost of land is $1,000 per acre, the acquisition of land is about $2,500,000. Access roads on the plant site for both truck and rail car add another $2 million to the total capital cost.

Costs were established on the basis of buildings able to withstand tornadoes and earthquakes, with use of the present state-of-the-art practice for contamination control, shielding, and remote handling. Capital is also dependent on the height to which the canisters are stacked. The standard 4 foot x 6 foot x 6 foot high canisters can be stored from one to five high and satisfy technical requirements for storage. If containers are stacked three high, the capital cost for a storage facility is $8.19 per cubic foot of material stored.

TABLE 35

CAPITAL AND OPERATING COSTS FOR LOW-LEVEL WASTE RETRIEVABLE SURFACE STORAGE FACILITY

PROCESSING FACILITY	ESTIMATED COST, $
Head End Material Handling	$4,100,000
Incineration Area	1,900,000
Evaporation Area	1,600,000
Waste Packaging Area	640,000
Auxiliaries	900,000
Total Direct & Indirect Capital Costs	$9,140,000
Design and Contingencies	6,860,000
Subtotal	16,000,000
Land Acquisition Cost	2,500,000
Access Roads for Truck and Rail	2,000,000
Total Capital Costs for Processing Facility	$20,500,000
STORAGE FACILITY	
Two Shielded Buildings	$10,000,000
Three Unshielded Buildings	7,500,000
Design Contingencies	6,100,000
Total Storage Facility Cost	$23,600,000
TOTAL COMPLEX CAPITAL COST	$44,100,000
ANNUAL OPERATING COSTS	$ 5,570,000
Processing	$ 5,570,000
Storage	1,330,000
TOTAL COMPLEX OPERATING COST	$ 6,900,000

Operating Costs

Operating costs were developed using the capital costs as the primary basis.

Total operating costs were estimated to be $10 per cubic foot of solids stored or $1 per cubic foot of solid waste as received, and $0.14 per gallon of liquid as received. Storage operating costs for the year 1980 were estimated to be $2.40 per cubic foot per year. The operating costs are dependent primarily on capital costs and operating efficiency. This study shows that the processing costs ($5,600,000/yr) will be the major cost item and the storage costs ($1,300,000/yr) the minor cost item per year, but the storage costs are accumulative over a period of years.

Design and Construction Schedule

The major elements involved in implementing a radioactive processing and storage facility include overall hazard and concept analysis, design, construction, acceptance testing, and environmental impact and licensing activities. The length of time required for impact statement and licensing activities is difficult to estimate, as no precedent has been set. If the disposal site is built and operated by a firm with experience in handling and disposal of radioactive wastes, safety analysis and environmental impact activity can probably be completed in two to three years. Assuming that detail design is not started until all licensing and environmental impact work is complete, an additional three years would be required before the plant could be operable at full capacity. Thus, the total time requirement would be about six years. If the environmental impact and licensing work can be conducted in parallel with some design and construction, the facility might be fully operational in a minimum of approximately five years.

Transportation Costs for Low-Level Radioactive Wastes

For estimating costs in 1972 dollars a highly simplified model is used. Estimated average values of all variables are used throughout. It is assumed that all waste is shipped a one-way distance of 300 miles, half by rail and half by motor freight. The waste is packed in expendable 55 gallon drums (type A), which are in turn carried inside a large type B overpack.[186] The reusable overpack has the standardized external dimensions of 8 x 8 x 20 feet, weighs 7.5 tons, and holds 42 drums weighing up to a total of 15 tons.

The capital cost is the purchase price of the reusable overpacks. The operating costs are assumed to have four significant components: freight costs (including the return of the empty overpack); purchase costs of the expendable drums; handling costs to pack and load the containers; and capitalization costs (amortization and interest).

The AEC has estimated that the annual volume of low-level wastes in 1980 will be 4,000,000 cubic feet per year.[189] Unfortunately, a corresponding weight is not given. It is assumed here that the average density is 70 pounds per cubic foot (including the weight of the drum). This value is an average of the values for compacted wastes (40 pounds per cubic foot)[224] and for cemented solid wastes (100 pounds per cubic foot).[227] With these bases, the weight of the low-level wastes produced in the year 1980 will be 120,000 tons. Assuming the 42 drums in a shipment are completely filled, there will be a total of 13,000 shipments per year.

Capital costs have been estimated as follows: the number of days required for a round trip (including loading and unloading) is nine days, the average of values for rail and truck.[216] Assuming an overpack utilization factor of one-half (the equivalent of idle time adding an additional nine days per round trip), each overpack is shipped about 20 times per year. Thus, a total of 630 overpacks is required. Assuming a cost of $2 per pound for the overpacks, the total capital cost would be $19,000,000.

To estimate the freight costs the rates for rail and truck loads of 44,000 pounds are averaged to give $2.10 per hundred weight. Assuming the return trip of the empty overpack costs one-half of the amount of the loaded trip, and considering the ratio of tare to net weight, the effective freight cost is $95 per ton of waste. The cost of the expendable drums, of which 540,000 are needed, is estimated to be $20 per each. To obtain the handling costs, it is assumed that it takes 40 man-hours of labor to pack and seal 100 drums and 24 man-hours to load an overpack for shipment. It is assumed that costs of unloading at the disposal site are included in the storage charges. Labor costs (including a multiplier for overhead) are assumed to be $10 per hour. Capitalization costs (amortization and interest) are assumed to be 20 percent of the capital costs per year. The resulting operating costs are given in Table 36 both in terms of the annual costs and various unit costs, including costs per unit weight, costs per unit volume, and costs per shipment.

TABLE 36

1973 OPERATING COSTS FOR TRANSPORTATION OF LOW-LEVEL RADIOACTIVE WASTES IN 1980

Category	Total $ (million/yr)	Per Unit Weight ($/ton)	Per Unit Volume ($/ft^3)	Per Shipment ($/trip)
Freight	11.4	95	2.9	880
Drums	10.8	90	2.7	830
Labor	5.3	44	1.4	410
Capitalization	3.8	32	1.0	290
Total	31.3	261	8.0	2410

Costs of Retrieval of Buried Low-Level Radioactive Wastes

A sizable quantity of low-level radioactive wastes has heretofore been direct-buried at commercial burial sites and at AEC facilities before 1970. Subsequent burials at AEC sites have been in "retrievable" drums with 20 year integrity.

A recent study[168] of the AEC site at Hanford, Washington, indicated costs of $45 million for retrieval of 5.2 million cubic feet of wastes in burial grounds at a rate of $8 per buried cubic foot.

At the above rate the cost of retrieval in 1980 of 2.5 x 10^6 cubic feet of buried commercial wastes with an accompanying tenfold volume of soil would be about $20 million, or eight times the cost of burial with present practices. Assuming a storage cost of $10 per cubic foot in a more permanent storage facility such as that designed in this study, the total cost of storage of the retrieved commercial waste and its accompanying soil would be about $250 million.

Thus the cost of a decision in 1980 to dig up the buried wastes would be on the order of $300 million, or more than one hundred times the cost of direct burial and much more than the cost of high integrity storage of the original wastes even without volume reduction by incineration.

CHAPTER CONTENTS

CHAPTER VI

SITING OF HAZARDOUS WASTE PROCESSING AND DISPOSAL FACILITIES

Page No.

BRIEF 251

GOALS AND OBJECTIVES OF SITE SELECTION 255

HEALTH, SAFETY AND ENVIRONMENTAL CONSIDERATIONS 256

DEVELOPMENT OF SITE SELECTION CRITERIA 257

EARTH SCIENCES 258

Geological Criteria 258

Hydrological Criteria 260

Soil Criteria 261

Climatological Criteria 263

TRANSPORTATION 265

ECOLOGY 267

HUMAN ENVIRONMENT AND RESOURCES UTILIZATION 269

SITE SCREENING PROCEDURES 271

Area Size Determination 272

INFORMATION SOURCES 272

REGIONAL DIVISIONS 273

COUNTY SUBDIVISIONS 274

RANKING AND WEIGHING SYSTEMS--DEVELOPMENT AND APPLICATION 276

Preceding page blank

CHAPTER CONTENTS (Continued)

Page No.

CHARACTERISTICS AND LOCATIONS OF EXISTING AND POTENTIAL SITES 279

Existing and Potential Hazardous Waste Sites 282

Site Monitoring Requirements 283

EVALUATION AND EXTENSION OF THE RATING SYSTEM 285

SITING CONSIDERATIONS AS RELATED TO DISPOSAL METHODS METHODS 286

Deep-Well Injection of Brines 286

    Zone of Rapid Circulation 289
    Zone of Delayed Circulation 289
    Subzone of Lethargic Flow 289
    Stagnant Subzones 289
    Dry Subzones 289

Land Burial Disposal 291

    Landfill Disposal 294

Ocean Disposal of Hazardous Waste Materials 296

Conclusions 303

CHAPTER VI

SITING OF HAZARDOUS WASTE PROCESSING AND DISPOSAL FACILITIES

BRIEF

Section 212 of the Resource Recovery Act of 1970 places the following requirement on this study:

> *....Such report shall include:...(4) an inventory of possible sites including existing land or water disposal sites operated or licensed by Federal agencies.*

This phase of the study requires assessment of potential waste processing and/or disposal sites on a nationwide basis, particularly for the 48 conterminous states, with the objective of selecting a wide assortment of candidate sites which best fulfill predetermined site selection criteria. These criteria principally involve major health, safety, and environmental parameters, as well as related potential economic trade-offs primarily associated with costs of transportation and offsite disposal of the processing plant's liquid and solid waste products. Such trade-offs should not compromise other considerations of site integrity, however. Other economic factors would include land values and the availability of adequate utility services (water supply, electrical energy, etc.). The guiding philosophy for choosing hazardous waste disposal sites has been to minimize any potential environmental consequences.

The development of initial site-screening criteria embracing the areas of health, safety, and the environment has drawn heavily upon expertise in a number of scientific and engineering disciplines. This task demanded a technical team with extensive practical knowledge of hazardous waste problems and their solutions, as well as the ability to recognize the many interrelationships among the criteria areas being defined and evaluated.

As a first step in establishing site selection or screening criteria, it was necessary to define the general criteria, which were determined to lie within four major categories: earth sciences and climatology (i.e., physical and chemical considerations); ecology; transportation; and human environment and resources utilization. The second step required further determination of the parameters to be assessed in each category, the quantitative "desirable-undesirable" limits associated with those parameters in the context of siting a hazardous waste processing/disposal site, and the pertinent nationwide information needed to maintain site-screening consistency among and between the various parameters and categories. Evaluation of this phase of the study naturally led to the question of the size of areas to be surveyed in the screening process.

Although a typical processing/disposal site will nominally occupy several hundred acres, it was not practicable to screen the entire country on such a small areal basis. Furthermore, the information needed for such a country-wide procedure (with very few exceptions, such as population density) is not available on such detailed, small-scale areas. The available information varies greatly in consistency within and between States, depending upon the organizations and objectives for which the information was collected. Thus, the country had to be surveyed on a manageable area-size basis using developed site-screening criteria and relevant data presented in a uniform nationwide manner. The county-size areal unit (3,050 counties in the conterminous U.S.) appeared to be of manageable size for the survey. Additionally, much of the needed information is presented on a county basis in such publications as the National Atlas.[228] These two favorable considerations resulted in a desirable balance between the number of areas to be evaluated and the amount and consistency of data readily available for each area.

The general approach of the site selection process was to first divide the U.S. into multi-county regions. Each county within a region was then ranked according to predetermined major factors and the rankings aggregated to obtain the total ranking. Spheres of influence for major industrial waste production areas served as the bases for regional delineation (see Table 37).

Ranking of counties according to specific characteristics in each of the four criteria categories, without regard to waste generation sources and amounts, is insufficient when considering transportation of wastes. It is necessary to consider both the transportation risk and economic aspects in selecting potential sites for processing/disposal facilities. To help compensate for this potential shortcoming, the country was divided into 36 regions with boundaries established primarily on the basis of equal distance from common waste sources and amounts, modified by physiographic considerations. The counties in each region were then evaluated and assigned relative rankings in each criteria area.

The ranking procedure which was developed recognized that the four criteria categories would not be of equal weight in determining site suitability. Indeed, such an equal weighting of evaluation parameters is rare in any decision-making process.

TABLE 37

INDUSTRIAL WASTE PRODUCTION CENTERS

1. Seattle, Tacoma, Everett, Bellingham, WA
2. Portland, OR; Vancouver, Longview, WA
3. San Francisco Bay Area, CA
4. Ventura, Los Angeles, Long Beach, CA
5. San Diego, CA
6. Phoenix, AZ
7. Salt Lake, Ogden, UT
8. Idaho Falls, Pocatello, ID
9. Denver, CO
10. Santa Fe, Albuquerque, NM
11. El Paso, TX
12. Fort Worth, Dallas, Waco, TX
13. Austin, San Antonio, Corpus Christi, TX
14. Houston, Beaumont, Port Arthur, Texas City, Galveston, TX
15. Oklahoma City, Tulsa, Bartlesville, OK
16. Wichita, Topeka, Kansas City, KS
17. Omaha, Lincoln, NB; Des Moines, IA
18. Minneapolis, St. Paul, Duluth, MN
19. Cedar Rapids, MI; Burlington, Dubuque, IA; Peoria, IL
20. St. Louis, MO; Springfield, IL
21. Memphis, TN

TABLE 37 (Cont'd)

22. Shreveport, Baton Rouge, New Orleans, LA; Jackson, MS

23. Mobile, Montgomery, AL; Tallahassee, FL; Beloxi, Gulfport, MS; Columbus, GA

24. Huntsville, Birmingham, AL; Atlanta, Macon, GA; Chattanooga, Nashville, TN

25. Louisville, Frankfort, Lexington, KY; Evansville, IN

26. Albany, Troy, Schenectady, NY

27. Indianapolis, IN; Cincinnati, Dayton, OH

28. Chicago, Kankakee, IL; Gary, South Bend, Hammond, Fort Wayne, IN

29. Midland, Saginaw, Grand Rapids, Detroit, Dearborn, Flint, MI; Toledo, OH

30. Columbus, Cleveland, Youngstown, Akron, OH

31. Pittsburgh, Johnstown, Erie, PA

32. Charleston, WV; Portsmouth, Norfolk, VA

33. Charleston, SC; Savannah, Augusta, GA

34. Winston-Salem, Raleigh, Greensboro, Charlotte, NC

35. Baltimore, MD

36. Philadelphia, Allentown, Harrisburg, PA; Camden, Elizabeth, NJ; Wilmington, DE

37. New York, NY; Newark, Paterson, NJ

38. Buffalo, Rochester, Syracuse, Watertown, NY

39. Boston, MA

40. Orlando, Tampa, Miami, FL

41. Little Rock, Pine Bluff, Hot Springs, AR

Accordingly, an analysis was carried out to determine the appropriate relative weights for each major criteria category. The final rating or score of a county within a region was the sum of the products of the rank within each criteria category and the weighting of that criteria category.

This screening, ranking and rating procedure was applied to all counties located in the 36 regions which cover the country. The output listing of all 3,050 counties, grouped by regional ratings (Appendix M) allows for the orderly and rational selection of counties within each region for the site-specific reconnaissance, and later detailed field studies required for validating an actual candidate site.

A number of Federal agencies assisted measurably in identifying 23 existing hazardous waste disposal sites and 44 tracts of Federally-owned land that appear to meet the criteria and could potentially be released for use as treatment/disposal sites. Generally, the latter were tracts of up to several thousand acres located primarily in the Western States.

A number of general monitoring requirements applicable to essentially all waste processing/disposal facilities were defined. Site-specific conditions, including treatment processes, would dictate the monitoring frequency and locations, as would any special monitoring and analysis requirements.

The technique developed and used for initial delineation of candidate sites appears to be practicable for use on a nationwide basis. Generally, the site selection process for an industrial plant location involves surveying relatively small intrastate areas for which detailed information may be obtainable. This would be the logical next step in the present scheme of selection once firm waste production data (sources and amounts) are accumulated for a specific, relatively small geographical area. No claim is made that the top candidate counties identified by the screening method employed are wholly optimum. Rather, the results indicate that a greater fraction of the land, or number of potential sites, in the high-ranked counties will be suitable for waste processing/disposal sites than in the low-ranked counties. The determination of specific highly suitable sites would, of course, have to rely upon the results of more detailed, site-specific analyses.

GOALS AND OBJECTIVES OF SITE SELECTION

The goal of site selection activities was to establish a practicable method for identifying, evaluating, and ranking potential processing and disposal sites and to apply the method nationwide to arrive at an initial list of area ranking with respect to site suitability.

Site selection studies for any industrial plant require an information base on the plant characteristics. Such data as land requirements, transportation needs, labor availability, utility services needs, plant capacity, processes and operations to be used in the plant, raw material sources, and effluents and waste products generated by the plant are necessary in establishing site selection criteria. Much of this background information was obtained from the effort on plant processes and facility design (Chapter IV). After obtaining these data, the criteria for site selection were defined, the major emphasis being placed on health, safety, and environmental considerations.

It was recognized early in this study that two types of sites based on somewhat different criteria would need to be identified: waste processing plant sites and long-term hazardous waste disposal/storage sites. The criteria differences for the two types of sites are mainly in the areas of earth sciences and transportation. Also, only a few sites would probably be required for long-term storage of the processed, isolated hazardous materials. In contrast, many sites may be required for the processing plants, because of the risk and economics involved in transporting large volumes of hazardous wastes from a multitude of generation sources.

HEALTH, SAFETY AND ENVIRONMENTAL CONSIDERATIONS

As the first step in developing the site selection methodology, a comprehensive list of potential health, safety and environmental criteria applicable to both processing and disposal/storage sites was prepared (Table A-90, Appendix M). These criteria embraced all possible site characteristics, including the processing and waste input-output considerations that are later used to determine the degree of relevance of the various criteria.

The list of potential siting considerations was assembled from a number of scientific and engineering disciplines, drawing upon the expertise of the program participants in their particular fields. At this initial stage of establishing site selection criteria, the intent was to assure that all criteria that might possibly be pertinent to site selection has been identified. The list was critically reviewed to determine the key characteristics requiring evaluation, to develop a rationale for their relevance, and to establish the quantitative bases for their evaluation. This criteria definition procedure benefited measurably from information that is being made increasingly available (primarily through local, State and Federal agencies) on hazardous waste disposal guidelines, surveys, and investigations.

DEVELOPMENT OF SITE SELECTION CRITERIA

Federal and State organizations, particularly, have recognized the possibility of present and future problems of hazardous waste processing and disposal. Significant efforts have been made to inventory and survey present disposal areas (primarily landfills) which receive industrial hazardous wastes, on the bases of short-term occupational health and safety and potential long-term waste decomposition and migration. In many cases, general criteria have been prepared and potentially favorable sites identified that satisfy the criteria. Most of these investigations are related to waste burial rather than processing considerations. Nonetheless, they were valuable in establishing and later verifying the earth sciences criteria.

The final general criterion areas considered appropriate for site evaluation, based on processing and disposal information, are listed below.

- Earth sciences
    - Geology
    - Hydrology
    - Soils
    - Climatology

- Transportation
    - Risk
    - Economics

- Ecology
    - Terrestrial life
    - Aquatic life
    - Birds and wildfowl

- Human environment and resource utilization
    - Demography
    - Resource utilization
    - Social impact

The next phase of the site selection sequence required that these criteria be evaluated in detail to determine the specific sub-items of concern and to arrive at a site ranking or value-function procedure.

A rationale was developed for each criterion area; the sub-items of concern were enumerated on the bases of processing and disposal data and the sizes of the areas to be evaluated. Details of area sizes are presented later in this chapter.

EARTH SCIENCES

Health and safety plant siting considerations attendant to the waste processing/disposal site and operations are heavily dependent upon earth science factors, including climatological considerations. Plant vessels and equipment and the buildings in which they are located are the first barrier to processing plant accidents and/or intentional or accidental releases of plant effluents. The surrounding natural environs form a secondary boundary. The major questions to be answered in this area are: what capabilities or barriers do the environs offer for mitigating the effects of accidents and effluent releases, while maximizing the effectiveness and minimizing the area and resources insulted; and, in doing so, what natural earth science resources might be removed from future beneficial uses? At disposal/storage sites where processed hazardous materials might not necessarily be stored in high-integrity containers, the immediate environs would be the primary barrier for assuring long-term isolation. The effects of earth science factors (e.g., foundation soils characteristics, water supply, tornado and earthquake potential) on the suitability of sites for plant construction and operation were of less importance, but were considered when undesirable conditions (such as mountainous terrain) were obvious.

Geological Criteria[229-250]

In establishing a technique for locating potential sites for hazardous waste treatment and disposal, analyses were carried out for three main geologic categories, geomorphic/topographic, tectonic, and stratigraphic. Although geology covers the interrelationship of all processes within the earth, in the context of this study hydrology and soils were considered to be separate important areas more directly related to site suitability. Hydrology considers the surface and groundwater from supply and pollution standpoints; soils considers the potential as a disposal medium and as a secondary barrier to accidental waste release. In this respect, both hydrology and soils can be quantified to some extent, even on a regional basis. The remaining geologic considerations must be treated more subjectively until a study develops into a very site-specific case.

Previous studies have begun to encompass the potential geologic problems associated with siting a waste disposal facility. Within the last decade, some common geologic criteria associated with solid waste disposal by landfill and land burial have emerged. Engineering geology, which is the application of physical geologic factors to promote efficient land use and insure stability of various structures and facilities, is routinely used in efforts to reduce or prevent problems associated with development and to reduce the impact of development on adjacent areas. By subjective integration of the criteria developed in these diverse areas, a more general set of geological considerations was developed to serve as a guide for evaluating the potential adequacy of sites for hazardous waste disposal systems on a regional basis.

Within each region, individual counties were first ranked on the basis of a mean slope index (average topographic relief). Counties with a predominance of high land relief (greater than 10 percent slope index) were ranked as least desirable. Areas of high relief are associated with active geological processes which generally impose severe restraints on land use: site engineering and construction costs would be relatively high; special roads or improved transport routes would be necessary (increasing system costs and potential spill hazards); and geology tends to be more complex and variable over local areas of site dimensions, therefore requiring more detailed studies. Folding, fractures, faults, and landslides often associated with high relief areas coupled with generally higher precipitation can also provide major recharge points for groundwater aquifers. Areas of flat slope (less than 1 percent) were also considered undesirable to some extent. These areas are located predominantly along floodplains of major streams, swamps, or in sinkhole areas. Natural drainage is poor, soils are generally unconsolidated, and competing land use for agriculture, recreation and ecologic preserves is more prevalent. If proper precautions are taken the land can be used for disposal sites, but at a higher cost and safety risk. Moderate slopes of 1 to 10 percent present the fewest land use constraints for hazardous waste processing/disposal sites.

Within any region the presence of a gross extent of surface or near-surface faulting resulted in a further modification to a county's rank. In areas where major faults are known there is a higher probability of localized faults and fractures being found during detailed site study. Faults and fractures can provide high permeability paths to the groundwater system and increase the potential for pollution from a waste processing/disposal system. Earthquake history, both frequency of occurrence and magnitude, was considered to be related to the potential for additional faulting in a given area. Areas of frequent earthquake occurrence also may prove unsuitable for deep disposal of waste products because of the potential triggering effect. Earthquakes per se are a perceived risk, requiring higher design costs and presenting difficulty with public acceptance.

The general rock sequences in each region were considered to be water supply sources and tertiary barriers to unplanned waste release. Centers of sedimentary basins were thought to be the most desirable because of the thicker stratigraphic sections available. Areas with outcrops of igneous and metamorphic rocks were looked upon as unfavorable because of the generally restricted amount of space available for subsurface disposal, even at shallow depths. Basalt, limestone and glacial outwash plains would be considered unfavorable because of associated high permeabilities and potential rapid hydraulic transport of wastes from an unplanned release. Limestone terrain and glacial outwash plains with thick unsorted gravel and floodplain deposits were also considered undesirable from the standpoints of site engineering and cost of construction, among others.

Hydrological Criteria[251-287]

According to the hydrological criteria used, the counties considered to be least desirable contain considerable floodplains, large bodies of water, or a high groundwater table. Counties judged to be most desirable for processing sites contain water supply sources (groundwater and/or surface water) continually providing at least 200 gpm of high-quality water, are underlain by noncarbonate consolidated rock aquifers, and lack most of the least-desirable characteristics listed above.

Floodplains are undesirable for two reasons, the first of which is related to safety. A processing site should logically be located above the elevation of the probable maximum flood to protect the plant, equipment, and wastes from being inundated. Secondly, floodplains are normally located in zones of high water tables, high wave runup, and permeable soils. In addition, structures located in floodplains act as restrictions to water movement.

Zones of high wave runup are undesirable because of the flooding potential and the associated accidental releases of hazardous materials. Zones of high water tables are undesirable because of the possibility of contamination of water supplies in the event of an accidental release. Greater depth of the water table provides more filtration of contaminants by the earth materials. Effectiveness of filtration is related to the type of material, the rate of fluid movement, and the distance traveled prior to entering a water supply system. The rate of fluid movement is dependent upon the permeability of the earth materials and the hydraulic gradient. In general, steep gradients are associated with low permeability, and vice versa. Steepness of the terrain also has an effect on the hydraulic gradient; in general, the steeper the terrain, the steeper the hydraulic gradient. A low hydraulic gradient is desirable because such a gradient accompanies flatter terrain. However, a low gradient might indicate a very permeable aquifer that is a valuable source of water. This would increase the risk of transporting a hazardous waste from the site.

It was estimated that each processing site must have an acceptable continuous water supply of 200 gpm. Quality of the water source determines the cost necessary to make it acceptable for use in the various plant processes.

Areas underlain by noncarbonate consolidated rock aquifers were considered superior to those areas underlain by aquifers of carbonate consolidated rock and by unconsolidated aquifers. The latter implies unconfined surficial aquifers, which are undesirable on the depth to water table basis. Carbonate (limestone) aquifers are generally undesirable because they can contain solution cavities and potential high permeability channels.

In summary, the prime hydrological consideration was the possibility that released liquid waste might enter and contaminate potable water sources. That probability, in addition to those constraints on releases attributable to plant design and operation factors, is related to the site conditions discussed above. Some areas of the country have been identified as already having contaminants in the local groundwater regime because of irrigation and other practices. Such sites were not downgraded in the site suitability ranking, since there exists the possibility of recovery in the future (by dilution mechanisms) if such detrimental practices are terminated. In some instances, candidate sites were downgraded because of the inability to obtain the nominal water supply required by the waste treatment facility.

Soil Criteria[288-342]

Soil characteristics were considered to be of importance in four categories: 1) as a secondary barrier to unplanned waste releases; 2) as a landfill disposal medium for relatively insoluble waste components; 3) as a surface upon which structural foundations are constructed; and 4) as a medium for growing agricultural plants rather than as a waste treatment plant site.

The following are the soil criterion categories considered for site ranking:

- Secondary waste barrier
    - Distance to groundwater
    - Sorption capacity (cation exchange capacity, pH)
    - Soil texture
    - Soil depth
    - Soil structure
    - Slope

- Landfill disposal medium

- Suitability for foundation construction

- Medium for agricultural purposes rather than as a waste site

Serving as a secondary waste release barrier is considered to be the most important function. Although accident prevention can be engineered into the facility, an absolute guarantee that no accidental waste solution release will ever occur cannot be provided; thus, this function of soil was given the highest priority. The movement (percolation) of a released solution through the soil occurs over a finite period of time; therefore, time is available in which to respond to a release. In addition, many waste components are sorbed by soils, which allows even longer response times.

The distance to groundwater and the soil depth criteria affect both solution movement and sorbed component movement. The greater the soil depth, the more time will elapse before groundwaters are contaminated by a release. The soil texture, soil structure, and slope criteria primarily affect the movement rate of liquids. The finer the texture, the lower the soil permeability, and the more slowly the liquids will move through the soil. Similarly, the more structured and layered the soil, the lower the soil permeability. The greater the slope, the faster the liquids will run off the soil surface and the slower will be the infiltration rate. These characteristics tend to spread any release over a much greater surface area. The soil sorption capacity criteria, as measured by the cation exchange capacity (CEC) and soil pH, affect only sorbable waste components. The greater the CEC, the greater the surface area of a soil, and the greater tends to be the sorption of all sorbable wastes including cations, anions, and organics. The higher the pH, the greater tends to be the sorption of many sorbable components, particularly the heavy metals.

The remaining three soil functions were judged to be of considerably less importance than the secondary barrier function. In these, engineering techniques can overcome the inadequacies of the soil. If the soil at the waste processing site is unsuitable for landfill disposal of insoluble wastes, for instance, this relatively low-volume waste can be shipped to another site for burial at minimal cost.

Soils which contain large percentages of montmorillonite clay or which consist primarily of silt-sized particles will result in higher foundation construction costs. The relatively low value of this category accounts for some nominal added construction costs attendant to such soils. The use of Class 1* agricultural land for the siting of a waste treatment plant permanently removes this land from the growing of agricultural crops. However, Class 1 farmland is plentiful in the United States, which lessens this impact. The relatively low importance of this category serves as an incentive to the use of land which is equally suited for the siting of a waste treatment plant but is not prime farmland.

Initial rankings were made for all counties within each of the 36 regions. The rankings were based on the criteria described above and were made by the integration of data from the National Atlas soil suborder, relief, and land-surface form maps. When sufficient soil surveys were available, they were used to calibrate key soil suborder, physiographic, and land surface form areas for making absolute county rankings.[343] Sufficient soil surveys were available for calibrating all soil suborder, physiographic, and land surface form regions for the Eastern United States and the Western States of Texas, Oklahoma, Nebraska, Kansas, North Dakota, and South Dakota. However, for the remaining eleven Western States it was necessary to rely upon a more generalized small scale map to fill in source data.

Climatological Criteria[344-348]

The meteorological criteria judged important in the siting of a hazardous waste processing plant vary locally, regionally, and nationally. For the county-unit size considered in the present study, only regional and national criteria could be considered.

---

*A soil capability classification is used by the Soil Conservation Service to group soils generally according to their suitability for most kinds of agriculture. Capability classes, the broadest grouping, are designated by the Roman numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use. Class I soils have few limitations restricting their use.

Meteorological factors used were mainly precipitation, wind roses, air pollution potential, and extreme weather potential (hurricanes and tornados). The precipitation index was based on the judgment that high precipitation values were undesirable. This was felt to be a defensible position for most plants based upon a variety of advantageous factors: simpler plant design; a potential for more effective operation of evaporative systems; less chance of an accidental release or leaching of spillage in concentrated form into the groundwater; better road conditions for transportation of materials; and the potential for combining the waste processing plant with a temporary or permanent storage facility at the site. On the other hand, low rainfall portends several disadvantages: if a potentially dangerous respirable material is released into the atmosphere, it may be desirable to have rainfall scavenge the material from the air. The present ranking, therefore, does not apply to plants where there is a strong potential for release of hazardous respirable material within the affected area.

In general, it would be better for most materials to be dispersed to low concentrations by the atmosphere as much as possible, and moderate rainfall rates would be desirable. Another potential argument against low rainfall is that in some situations a plant may have a low-level continuous output of material that is deposited on the surrounding region; a long-term surface buildup of the material may occur if there is not sufficient rainfall to remove it, at least occasionally, from the surface. Hence, although it is generally true that sites with lower rainfall rates are most desirable, sites with very low rainfall may also be undesirable if the analyses for a particular plant show that low-level routine releases of hazardous materials might build up in the environment. In the dryest regions routine releases become more critical in the plant design from a meteorological viewpoint. However, considering the nature and design of the hazardous waste processing plants, these considerations were not deemed major, and the weighting was used to favor sites with low annual mean rainfall rates. Primarily, maps and values published by the Department of Commerce, Environmental Sciences Services Administration were used as data sources.

The problem involved in using published wind roses at the presented scale was mainly concerned with the relationships between the trajectory from the site and population densities. A population-weighted index for the surface wind rose was prepared for each site; populations for adjacent sites were used for the weighting. In the East where counties are fairly small, the index was used without changes; however, in the larger counties in the West these criteria lost much of their validity, and were therefore modified. An index based on winds' potential trajectories over population centers in the larger counties was used. Published national maps of air pollution potential were used in the ranking. Generally, sites with small air pollution potentials were deemed to be most desirable from the consideration of both routine and accidental releases.

Regions of high tornado potential were given lower rankings. Plant design, transportation hazards, and perceived risks were the major factors influencing this criterion. Hurricane potential was similarly taken into account in the rankings.

TRANSPORTATION[349-358]

Two basic considerations in transportation of hazardous wastes for processing and disposal are the hazards of transporting the waste and the economics associated with transportation. Economic variables considered in criteria selection include relative volumes of wastes generated at given points, relative transportation distance between major waste generation points, the transportation network of the area being ranked, and the transportation link between the area being ranked and other waste generating points. Risk variables considered in criteria selection include the distance traveled, type of terrain traversed, and number and sizes of metropolitan areas traversed during transit of waste.

The criteria used in the transportation ranking were as follows:

(1) the number and relative size of major waste production areas within an approximate 250-mile radius of the county being ranked;

(2) the transportation link between the county being ranked and the major waste production areas;

(3) the transportation network of the county being ranked;

(4) the relative rail distance between the county being ranked and the major waste production areas; and

(5) the route of travel between the county being ranked and the major waste production areas, including the number and relative sizes of metropolitan areas along the route and the terrain traversed over the route.

The number and relative sizes of major waste production areas within the sphere of influence of the county being ranked were utilized primarily as a measure of waste volume for comparison with other waste production areas. A distance of about

250 miles was superimposed upon the criteria as the geographical transport limit for one day. Beyond this limit the transportation costs increase substantially as a result of overnight expenses for drivers and the potential hazard increases when the loaded wastes are stored on the carrier overnight. The volume of waste produced within a region as well as the distribution of the waste production is considered to be of significant economic importance. Relative waste volumes used in this phase of the study were typically based upon the waste production areas identified, the population size of the waste production area, and knowledge of the industrial intensity of the waste production area.

The transportation link between the county being ranked and major waste production areas within a 250-mile radius was used to measure the efficiency of the access between areas. Links were determined by mainline rail trackage and major highway access; rail linkage was typically the most critical. The determination of transportation linkage was primarily based upon the directness of the link.

The transportation network of the county being ranked was used to determine the quality of access to other areas. Major considerations within this criterion were the availability of rail and major highway access in both north-south and east-west directions.

The measure utilized to account for transport distance was the relative rail distance between the county being ranked and major waste production areas within a 250-mile radius. Rail distance was used because rates for freight movements, including motor freight, are typically based upon rail miles. Distances between the point of consideration and major waste production areas are important for several reasons. Distance is economically important because transport cost for any given volume is normally some function of distance. Distance is also an important consideration in determining risk because of the relationship between risk and distance traveled; risk of accident typically increases as distance increases. Transport handling, such as switching, normally increases with distance and correspondingly increases the risk. Also, the time associated with transport increases with distance and thus increases the risk because of the additional exposure to potential accidents. The routes of travel between the county being ranked and major waste production areas within a 250-mile radius were utilized to assess risk. Two major considerations were associated with this criterion: the first was the number and relative size of metropolitan areas along the route. This aspect was considered because risk normally increases with the number and sizes of metropolitan areas to be traversed. Metropolitan areas introduce two important risk characteristics, people and congestion. The severity of any accident increases with the number of persons exposed to the accident and the probability of accident increases with traffic volume. The second major consideration was the type of terrain traversed along the route. The more rugged the terrain, the greater the potential for accidents.

Each of the criteria listed above was considered in the ranking of each county. Quantitatively evaluating each of the criteria as it related to a particular county ranking was determined to be infeasible. This decision was influenced by the scope of data requirements, data inadequacies, and the need to consider criteria in a matter peculiar to a given region, i.e., the transportation profile of each region. As a result of these constraints, each criterion was objectively evaluated for each county in the United States. The final rank assigned to a county is an evaluation of how well the county meets the criteria in relation to other counties in the region and also in relation to counties serving major waste production areas within a 250-mile radius.

Generally, counties that ranked high were considered to be the best locations to serve as collection points for wastes generated both within and outside the region. They have excellent transportation networks with links to all or most waste production areas within a 250-mile radius. They are typically the best sites available in the region based on the criterion under consideration. Conversely, counties with low rankings were considered unacceptable from a transportation perspective. Typically, they fit one of the following situations: no rail facilities, dead-end rail facilities, more than 250 miles to any major waste production area, or distance and risk factors imposed by terrain and other physical landforms sufficient to warrant the county as unacceptable.

ECOLOGY[359-362]

Ecosystems are highly complex and consist of many physical, chemical, and biological components inter-connected by a multitude of functional pathways. In attempting to characterize ecosystems it is useful to limit the description to the predominant parts of the system. The indicator approach is commonly used when it is neither possible nor desirable to make appropriate measures or estimates of the status of all the components of the system. Instead, selected groups of species, habitats, or other important components are examined in some detail and used as an index to estimate the overall quality or condition of the ecosystem.

Land use has provided such an indicator for this study. The inference of ecological quality from land use involves a logical, two-step process. The land-use patterns followed here mapped the major existing vegetation types in the United States and their uses, e.g., cropland, ungrazed desert shrubland, ungrazed forest, and woodlands. The various vegetative types and their uses are excellent indicators of the environmental quality of a specific region. Vegetation, by the nature of the photosynthetic process, is the source of organic energy for an ecosystem. The productivity of the vegetation in terms of energy or biomass is important in regulating the numbers and kinds of animals which can exist in the ecosystem and in the use man can make of that system. Vegetation also provides breeding and nesting sites and protective cover for animals, thus enhancing the quality and utility of the system.

Another advantage of using land-use patterns as an ecological indicator is that it gives some measure of the degree of interference man has imposed upon the natural environment. For example, urban development represents an extreme departure from the natural state and as such has little value as a smoothly functioning balanced ecosystem.

Fifteen types of land use were recognized. These were ranked in order of increasing ecological importance as follows.

- Urban
- Desert shrubland, ungrazed
- Barren land, alpine meadows above timberline
- Desert shrubland, grazed
- Open woodland, grazed
- Subhumid grassland and semiarid grazing land
- Cropland
- Irrigated land
- Cropland with grazing land
- Cropland with pasture, woodland, and forest
- Woodland and forest with some cropland and grazing
- Forest and woodland, grazed

- Forest and woodland, ungrazed
- Swamp
- Marshland

Areas which ranked high for the siting of industrial facilities such as hazardous waste processing plants were low in ecological quality because of either urban development or physical-chemical limitations imposed by natural conditions. Agricultural lands dominated an intermediate grouping. Here, disturbance from man has decreased, but the monoculture results in a less diverse system with reduced stability and resiliency. Forests, which characterize the third grouping, represent an improvement in both diversity and stability over the other two groups. Finally, swamplands and marshes, because of their high productivity and extreme sensitivity to disturbance, were found to be incompatible with the processing plants and disposal/storage facilities.

The major land-use types were determined for each region from a land-use map of the fifteen recognized types. Few regions were found to contain more than four or five types. The land-use type in the region most suitable for industrial development was assigned the highest ranking and the least suitable land-use type was given the lowest ranking. Completely incompatible swamp or marshlands were specifically noted. Land use types of intermediate suitability were given intermediate rankings compatible with their positions in the above list.

Using an overlay showing the counties in a region, the proportion of a county's area in each land use type was estimated. The sum of all land use type ranks times the proportion of that type in the county gave the overall regional ranking for that county. These overall ecological rankings are indicative of the probability of finding an actual site (about 200 acres) within the county. As discussed earlier, this does not mean that low-ranked counties cannot have excellent sites; rather it indicates that in high-ranked counties the probability of being able to find an ecologically suitable site is greater than in the low-ranked counties.

HUMAN ENVIRONMENT AND RESOURCES UTILIZATION [363-378]

The development and assessment of pertinent criteria in this category, particularly those related to the human environment, are especially difficult. Evaluation of the effects of man's actions on man has always required a high degree of judgment which has been complicated by historical and geographical variations in societal desires. The establishment of criteria and their relative importance to the human environment, therefore, was approached from two viewpoints. The first includes an analysis of factors which can be quantified easily (population distribution, recreational demand) and which lean heavily toward health and safety considerations (site distance from natural areas, population concentrations). The second viewpoint considers those factors which are in the difficult-to-quantify area of public attitudes and acceptance. These were assessed mainly by using demographic data to determine on a county-by-county basis site suitability with respect to existing and projected population density and characteristics such as age, tenure, income and education. Generally, large urban residential areas such as Standard Metropolitan Statistical Areas (SMSA) were considered unsuitable, although it was recognized that many of these have associated well-planned industrial parks which might accommodate waste processing plants. Conversely, much industry is ill-situated in such areas, particularly industry about which residential areas grew early in this century. While large centers of population generate the bulk of the wastes (implying favorable transportation considerations), there is no identifiable uniform attitude on the part of political entities or the populace concerning hazardous waste processing plants located nearby, even in the industrial parks. Also, even though the real risk for such facilities will be minimized by design and operational planning, the perceived risk will be high and may well dictate the exemption of highly populated areas from consideration.

Other human environment parameters that were deemed unfavorable were: non-industrial developed shorelands (because of their value for open space, recreation, and other human uses and because of current protective legislation); areas of high scenic and recreational interest; proximal international boundary areas; counties with significant numbers of historical or cultural features; and counties with high densities of schools, hospitals, and similar sensitive facilities. In the ranking system of 0 to 5 which will be discussed later in this chapter the 0 ranking provided a special "flag" for counties where political or public attitudes might have a significant impact on the county's relative rank.

Although not included in the ranking or value judgment phase of this study, public acceptance of waste processing and disposal/storage sites is of concern and means for reflecting this factor should be integrated into the site selection process.

Development and evaluation of criteria in the area of resource utilization presented some problems. It had to be done carefully to assure that the criteria in this category did not overlap or include those in other categories, particularly earth sciences, ecology, and the human environment, thereby resulting in double-accounting.

Included in the definition of resource uses were minerals and their extraction, agriculture (aside from ecological considerations), manufacturing, recreation/tourism commerce, and unique commercial, industrial, residential, and other developments. Compatibility was determined primarily by considering dominant resource utilization patterns and potential and projected demands within each county.

The distinction is rather fine between several of the criterion parameters noted in this category and those included in the human environment category. In addition, many of the information sources required in the value ranking process are identical and, in some cases, integrate several of the parameters in the data presentation. For this reason the two categories were grouped together as one criterion.

SITE SCREENING PROCEDURES

Two approaches were assessed for site screening, a search technique and an overall survey technique. The search approach involves looking for specific sites that appear to satisfy the selection criteria as closely as possible. This is a somewhat random elimination procedure, although some degree of organized assessment is possible. For the most part, it requires searching the country using available appropriate literature to identify candidate sites of substantial size (but smaller than county-size) which satisfy as many of the criteria as possible. With this method, however, a vast amount of literature concerning past studies which varies greatly in depth, breadth and accuracy among sites must be acquired and evaluated and many good candidate sites will undoubtedly be overlooked because of a paucity of information. Some of the interrelationships and tradeoffs between criterion areas may be greatly subjugated. The search technique is most applicable for site selection in relatively small regions after they have been identified in the nationwide survey, and it would logically lead into the site reconnaissance survey.

With the nationwide survey approach used in this study no sites are overlooked in the site screening; thus the bias involved in considering only candidate sites for which specific relevant information is already available is eliminated. Potential problems with this method, some of which can be resolved satisfactorily, are concerned with the uniformity, detail and accuracy of the needed evaluation data, the size of the areas into which the country is divided, and the potential interactions between these areas (and between larger regional divisions) in the final ranking procedure.

Area Size Determination

Having decided that the nationwide survey approach was best for the initial site screening, it was then necessary to determine the appropriate areal subdivisions. There was a need for balancing the site ranking scheme in terms of both the number of areas to be considered and the number of criterion areas to be evaluated. In combination, the product of these two factors determined the size of the evaluation matrix. For example, if the country is divided into 200-acre areas, the nominal size of a waste processing/storage site, the total number of areas to be evaluated would be on the order of ten million. Clearly, this would result in a matrix of unmanageable size; but, more importantly, the task of acquiring the needed criterion data would be impossible. It was therefore felt that the size of the areas had to be enlarged to make both matrix size and data collection practicable.

INFORMATION SOURCES

A myriad of information sources exist that are potentially useful in determining how suitable sites meet site selection criteria. The areal coverage of this information varies from small plots of only several acres (e.g., studies for locating or investigating the operation of a specific landfill site) to regional areas (e.g., studies describing the water resources of a major river basin). Furthermore, the details and objectives of these investigations vary to a corresponding degree; some examine only one feature or consideration (e.g., water supply or pollution potential), others examine a host of considerations (e.g., foundation soils, water supply, adjacent land uses, climatic conditions, transportation access). Although much of this information might be applicable to site selection, there is no workable method for collecting, sorting and then evaluating the data contained in these many publications on a consistent and efficient basis. The task of just determining the value of the information in a single criterion area would be insurmountable. Also, such information resolution is often complicated by opinion differences of investigators on the interpretation of study results from essentially identical studies.

Information bases were sought that would present the required data on a nationwide scale, yet in adequate detail to differentiate between the areas selected for evaluation; that would be accurate, current and acceptable to the scientist, engineer and layman, and that would be consistent and uniform in resolving the many input data from which the results were derived. Publications such as The National Atlas of the United States, Annual Commercial Atlas and Marketing Guide, Climatic Atlas for the United States, population census reports, and others as noted in the reference section do provide the information needs in the optimum form for the nationwide site selection evaluation. Additionally, these comprehensive publications represent a great amount of effort expended by experts in the various fields who have access to past and current literature and whose interpretation and integration of data is in a constant state of review and updating.

REGIONAL DIVISIONS

Information on waste generation sources and amounts showed considerable variation from region to region. On a percentage basis, the relative amount of waste generated in each of the nine census regions is estimated as follows:

Census Region*	Percent of Total Generated Waste*
1 - New England	4
2 - Mid-Atlantic	19
3 - East North-Central	27
4 - West North-Central	6
5 - South Atlantic	8
6 - East South-Central	5
7 - West South-Central	18
8 - Mountain	2
9 - West	11

*Data source: waste generation tables, Chapter III.

This unequal distribution of wastes across the country emphasizes that waste treatment plants may vary in size, number, and concentration as well as in the order in which they might be constructed and operated. Transportation risks and economics, primarily, dictate that processing facilities be provided on a regional basis. This called for the definition of a logical regional division of the country and an evaluation of all the areas within each region for site suitability. In the first step the industrial waste production areas were listed by major city and adjacent-city groupings.

The conterminous United States was subdivided into 36 waste treatment regions based upon distances from the 41 identified major industrial waste production centers (Table 37). A maximum of about 200 miles in the East and 250 miles in the West was set as the allowable distance between the treatment site and industrial waste production centers in a given subregion. These are the maximum distances a truck could haul a waste load and return in a shift-day. It is expected that a truck in the

CHAPTER CONTENTS (Continued)

Page No.

LANDFILLS 118

BRINE DISPOSAL 123

PROCESS PERFORMANCE LEVELS 124

RESOURCE RECOVERY 124

Candidate Recovery Materials 127

- Recovery of Heavy Metals 128
- Recovery of Waste Solvents 130
- Recovery and Utilization of Waste Oils 133

Reprocessing 134

Fuel for Evaporation/Concentration of Aqueous Wastes 134

Fuel for Boiler Plant 135

EFFLUENT MONITORING 135

TRANSPORTATION OF WASTES FOR PROCESSING 137

Cost Estimates 138

- Processing Facilities 138
- Disposal Costs 142

CHAPTER IV

HAZARDOUS WASTE MANAGEMENT METHODS AND COSTS

BRIEF

Treatment capabilities required of hazardous waste processing facilities will depend on the types and volumes of hazardous wastes generated in the vicinity of the facility. Broad treatment capabilities may be required for a facility located in a heavily industrialized area whereas only limited treatment capability may be required for a facility located in a lightly industrialized area. For this phase of the study a model facility capable of processing a wide variety of hazardous wastes (excluding radioactive and DOD wastes as covered in Chapter V) was considered. Conceptual design and cost estimates were prepared for a complete waste management system to process and dispose of the wastes. In addition to treatment and disposal, peripheral functions such as transportation, storage, and environmental monitoring were considered.

The basic objective of waste treatment at a hazardous waste processing facility is the conversion of hazardous substances to forms which are acceptable for disposal or reuse. Since the majority of anticipated wastes will be complex mixtures containing several chemical species, treatment for removal and/or conversion of constituent nonhazardous substances will also be required in order to comply with pollution control regulations. In many instances, the volume of nonhazardous substances in a waste will dictate the type of treatment process used and will entail the most significant operational costs.

Broad treatment capability will permit the processing of many nonhazardous wastes, achieving for the individual producer the advantage of economy of scale. In order for a privately operated facility to maintain a competitive position in the waste processing field, it is anticipated that all wastes which can be processed will be accepted; in fact, profitably. Inclusion of nonhazardous waste processing also increases opportunities for recovery of metals, oils, and solvents.

It must be emphasized that the model facility developed in this study was designed primarily for processing hazardous wastes and, therefore, processing facilities capable of handling both hazardous and nonhazardous wastes may be different in many respects. A number of factors will dictate individual design variations for a given facility. Foremost will be the volumes and types of wastes, both hazardous and nonhazardous, that will be received for processing. One facility may require many different processes whereas another may require only one. Furthermore, processes selected for the model facility are not intended to be all-inclusive. A wide variety of additional processes are available to meet the needs of all locations and processive facilities.

Potential treatment processes and disposal methods investigated in the TRW study[19] will be discussed and the rationale given for selection of the particular processes for the model facility developed here.

DESCRIPTION OF SITE TYPES

Hazardous Waste Processing Facility

The model hazardous waste processing facility incorporates the various waste treatment functions from which effluents can be discharged in the vicinity of the processing facility. The facility is basically a chemical processing plant designed to operate safely in a normal industrial area. Effluents from the facility will be required to meet applicable local water and air standards. Local solid waste disposal will be limited to nonhazardous wastes which are acceptable for burial in a conventional landfill, which may be located near the processing facility. In general, nonhazardous waste brines will be disposed of by ocean disposal or deep well injection to avoid potential quality impairment of fresh water sources. Land disposal of these brines is a less desirable alternative method which can be used only in arid regions, and infrequently there. Transporting the brines to an arid land disposal site would in most cases be more costly than transporting these materials to deep well or ocean disposal sites. Since disposal of brine to land is detrimental to soil quality, deep well or ocean disposal are more desirable alternatives.

The facility will also contain equipment and structures necessary for transporting, receiving, and storing wastes and raw material. Another important feature will be a laboratory to provide analytical services for process control and monitoring of effluent and environmental samples and pilot scale testing services to assure satisfactory operation of the processing plant. The latter normally is not required in a conventional chemical processing plant but, due to the highly variable nature of the waste feed in this case, pilot scale testing is considered essential.

Hazardous Waste Disposal Facility

The hazardous waste disposal facility will consist of a secured landfill and the appropriate equipment and structures for burial and surveillance of the hazardous solid wastes. Secured landfills will be located away from population centers in areas of minimal land use. Although the hazardous waste sludges will be incorporated in asphalt or other materials to reduce leachability, secured landfills will be located where the potential for groundwater contamination is low. These landfills are to be isolated from public use and kept under perpetual surveillance to assure that long-term control is maintained.

PROCESS SELECTION

Potential Processes

A list of 45 currently employed waste treatment techniques (Table 10) was prepared by TRW Systems Inc.[19] from the Booz-Allen report[10] and other literature references. TRW then selected the 16 processes (Table 11) most applicable to the treatment of hazardous wastes, developed process profiles for each, and subjected them to detailed study.

Process review and selection work in the current study combined TRW Systems' process files and recommendations for incorporating 16 unit processes in the disposal site system with additional analysis of selected hazardous constituents and waste streams to derive a conceptual diagram of a model hazardous waste processing facility. Design objectives for the model facility included broad treatment capability to permit processing of all significant volumes of hazardous wastes generated across the country. Process effectiveness and flexibility were important selection criteria.

Selected Processes

The objectives of waste processing at the model facility are the removal of hazardous and polluting substances and/or conversion of these substances to forms acceptable for disposal or reuse. Based upon the hazardous wastes identification portion of this study described in Chapter III, it was determined that in order to accomplish these objectives the model facility must include treatment processes for:

- neutralization of acids and bases;
- oxidation of cyanides and other reductants;
- reduction of chromium-6 and other oxidants;

TABLE 10

CLASSIFICATION OF WASTE DISPOSAL/RECOVERY PROCESSES AS DEVELOPED BY TRW[19]

I. Physical Treatment Processes

A. Gas Cleaning

- Mechanical Collection
- Electrostatic Precipitation
- Fabric Filter
- Wet Scrubbing
- Activated Carbon Adsorption
- Adsorption

B. Liquid - Solids Separation

- Centrifugation
- Clarification
- Coagulation
- Filtration
- Flocculation
- Flotation
- Foaming
- Sedimentation
- Thickening

C. Removal of Specific Components

- Adsorption
- Crystallization
- Dialysis
- Distillation
- Electrodialysis
- Evaporation
- Leaching
- Reverse Osmosis
- Solvent Extraction
- Stripping

II. Chemical Treatment Processes

- Absorption
- Chemical Oxidation
- Chemical Precipitation
- Chemical Reduction
- Combination and Addition
- Ion Exchange
- Neutralization
- Pyrolysis

TABLE 10 (continued)

III. Biological Treatment Processes

- Activated Sludge
- Aerobic Lagoons
- Anaerobic Lagoons
- Spray Irrigation
- Trickling Filters
- Waste Stabilization Ponds

IV. Ultimate Disposal Processes

- Deep Well Disposal
- Dilute and Disperse
- Incineration
- Ocean Dumping
- Sanitary Landfill
- Land Burial

TABLE 11

WASTE DISPOSAL/RECOVERY PROCESSES SELECTED FOR APPLICATION TO HAZARDOUS WASTES TREATMENT OR SPECIFIED BY TRW[19]

- Reverse Osmosis
- Electrodialysis
- Dialysis
- Land Burial
- Deep Well Disposal
- Ocean Dumping
- Sanitary Landfill
- Combustion Processes
- Pyrolysis
- Ion Exchange
- Activated Sludge
- Trickling Filters
- Aerated Lagoons
- Anaerobic Lagoons
- Spray Irrigation
- Waste Stabilization Ponds

- removal of heavy metals;
- separation of solids from liquids;
- removal of organics;
- incineration of combustible wastes;
- removal of ammonia; and
- concentration of waste brines.

Treatment and Disposal

Processes selected for inclusion in the model facility are presented in Table 12 and discussed below.

Chemical Treatment

A common characteristic of many hazardous wastes is the presence of acidic or basic constituents which require neutralization prior to further processing or disposal. Neutralization is carried out in part by reacting acid wastes with basic wastes. However, it is expected that acid wastes will predominate,[48] necessitating substantial additions of reagent base for neutralization. Neutralization will be accompanied by the precipitation of heavy metals including those in the hazardous category such as arsenic, cadmium, mercury, and antimony. Most heavy metals precipitate as hydroxides or hydrous oxides upon neutralization and exhibit low solubilities in water. Neutralization-precipitation followed by clarification is effective for reducing heavy metal concentrations in metal finishing wastes to the 1-10 mg/l range.[49,50,51] Arsenic does not precipitate as a hydroxide or hydrous oxide but will coprecipitate with heavy metals (e.g., Fe^{+3}) as the arsenate.[52] Since further reduction in the heavy metal concentration below the 1-10 mg/l range is required to meet water quality standards, an additional precipitation step utilizing sulfide is included.[53] Sulfide precipitates of heavy metals are highly insoluble. Separation of the precipitated solids from the liquid phase will be accomplished by flocculation, sedimentation, and filtration techniques widely used throughout industry[50,51,53-56] and in municipal wastewater treatment plants[57-59] for solid-liquid separation.

In addition to neutralization-precipitation, chemical treatment must also involve processes for treating cyanide and chromium-6 bearing wastes. Although these wastes may be treated by a wide variety of processes,[49-51,60-73] large plants generally use chlorine oxidation of cyanide and sulfur dioxide reduction of

TABLE 12

PROCESSES SELECTED FOR INCLUSION IN MODEL HAZARDOUS WASTES PROCESSING/DISPOSAL FACILITY

Treatment Processes	Disposal Processes
Neutralization	Ocean Disposal
Precipitation	Deep Well Injection
Oxidation-Reduction	Landfill
Flocculation-Sedimentation	
Filtration	
Ammonia Stripping	
Carbon Sorption	
Incineration	
Evaporation	

chromium-6. Consequently, these processes were selected for use in the model facility.

Ammonia Stripping

This process is included largely for the removal of ammonia which is expected to appear in substantial qantities in some wastes. Although ammonia is not a hazardous substance its removal is required to meet pollution control regulations. Ammonia stripping is a standard treatment process for removing relatively large quantities of ammonia from aqueous solutions.[74,75] Low concentrations of ammonia may be adequately treated by oxidation with chlorine.

Organic Removal

The carbon sorption process[76-81] was selected in preference to biological treatment processes for the removal of soluble organics from incoming waste streams for the following reasons:

1. Biological systems can operate effectively only within narrow ranges of flow, composition, and concentration variations. These conditions are impossible to fulfill at a site where incoming organic containing waste streams are highly variable in composition and concentration.[82] The situation is aggravated further by projected campaign scheduling of process operations.
2. Biological systems generally do not work on solutions containing more than 1-5 percent soluble salts.[83] The solutions anticipated at a disposal site will contain from 10-20 percent soluble salts.
3. Systems which provide the full range of biodegradation facilities usually necessary would require large land areas.[84]
4. The presence of numerous toxic agents poses a constant threat of culture destruction.[82] Resulting acclimation and start-up times would be prohibitive.

In general, a biological system is an economically viable answer to organic destruction only when the waste stream is large, continuous, and fairly constant in its composition.

Evaporation

Evaporation was selected as the most economically favorable process for concentrating brine wastes. Concentration of nonhazardous brine wastes will not be necessary in areas where the cost of transporting these wastes for ocean disposal or to deep well injection sites is low. Other processes such as ion exchange, reverse osmosis, dialysis, and electrodialysis are not suitable for concentrating strong brine solutions.

Incineration

Incineration is routinely used throughout industry for destroying combustible wastes and is the obvious choice for treatment and disposal of hazardous combustible wastes. High temperature oxidation is one of the most effective means of destroying this type of waste. Further, incinerators can be designed to process both liquids and solids, the latter assuming many different shapes and sizes.

Disposal Processes

Disposal methods selected for the model system include landfill for solid wastes and ocean disposal and deep well injection for liquid wastes. Two types of landfills have been considered: secured landfills located away from population centers in areas where land use is minimal and potential for groundwater contamination is low and conventional landfills located at or near the treatment facility. The secured landfill is to be used for disposing of solid wastes containing hazardous substances such as arsenic, mercury, selenium, cadmium and antimony. Conventional landfills may be used for disposal of solid wastes containing no significant concentrations of hazardous substances.

Ocean disposal and deep well injection are recommended for disposal of nonhazardous waste brines from the treatment facility. The combined wastewater processed at a typical facility is expected to have high concentrations of dissolved salts consisting largely of sulfate and chloride salts of sodium, potassium, calcium, and magnesium. Ocean disposal is the most attractive method because these salts become undetectable against the natural background when completely mixed into the ocean.[85] Deep well injection is a practical alternative to ocean disposal in areas where suitable geological formations exist and the cost of transporting the wastes to an ocean disposal site is high. Caution must be exercised when using the deep well injection method to avoid contaminating fresh water supplies.

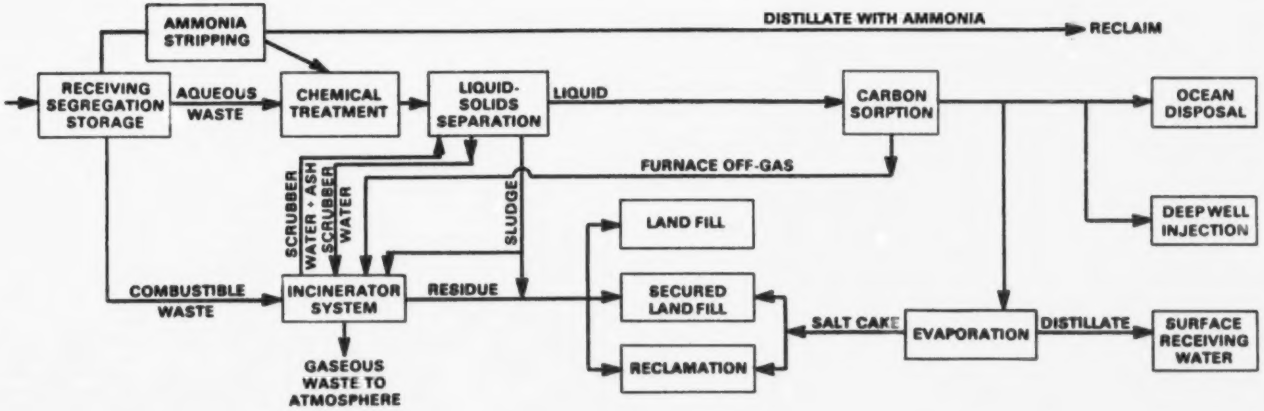
PROCESS DESIGN

Treatment Facility

A conceptual flow diagram which integrates the various treatment steps in modular form as illustrated in Figure 2 was developed

FIGURE 2

CONCEPTUAL MODULAR FLOW DIAGRAM


AMMONIA STRIPPING
DISTILLATE WITH AMMONIA
RECLAIM
RECEIVING SEGREGATION STORAGE
AQUEOUS WASTE
CHEMICAL TREATMENT
LIQUID-SOLIDS SEPARATION
LIQUID
CARBON SORPTION
OCEAN DISPOSAL
FURNACE OFF-GAS
DEEP WELL INJECTION
SCRUBBER WATER + ASH
SCRUBBER WATER
SLUDGE
LAND FILL
COMBUSTIBLE WASTE
INCINERATOR SYSTEM
RESIDUE
SECURED LAND FILL
SALT CAKE
EVAPORATION
DISTILLATE
SURFACE RECEIVING WATER
GASEOUS WASTE TO ATMOSPHERE
RECLAMATION

for the model hazardous waste processing facility. The flow pattern represents that normally expected. However, additional piping was included to provide flexibility. In the normal flow pattern, wastes with high concentrations of ammonia or ammonium salts are diverted from storage to the ammonia stripper for ammonia removal. The ammonia is steam distilled and appears as a concentrated stream from the condenser while the stripper bottoms, which are essentially free of ammonia, are routed to the chemical treatment module. The chemical treatment module serves several functions including receiving, storage and distribution of chemical reagents, oxidation of cyanides and other reductants, reduction of chromium-6 and other oxidants, neutralization of acids and bases, and precipitation of heavy metals. The liquid-solids separation module involves sedimentation as the first step followed by vacuum filtration for dewatering of sludges and multimedia filtration to remove residual particulate matter from the supernatant liquid. Filter effluent is then routed to the carbon sorption module for organic removal and finally to the evaporation module if concentration of the brine is desired. The brine may be concentrated either to a pumpable slurry or to a salt cake depending on the mode of transportation which will be used to ship this material to a disposal site.

Combustible wastes are processed in an incinerator which includes off-gas cleaning equipment to remove acids and particulates. Ash from the incinerator is transferred as a slurry to the liquid-solids separation module together with scrubber and quench wastewater. Sludges from the liquids-solids separation module, if relatively free of hazardous metals, are buried in a local landfill. Sludges which contain substantial quantities of hazardous heavy metals (except Cr^{+6}) are shipped to a secured landfill. Waste brines and salt cakes will be disposed as previously discussed.

Preliminary estimates called for a design capacity of 623 tons per day of waste for the typical medium sized facility. The wastes include 122,000 gpd of aqueous wastes including inorganic sludges and 74 tons per day of wastes to be incinerated. A discussion of processing and disposal methods follows.

Receiving, Segregation, and Storage Module

Upon receipt at the facility, prior to unloading and transfer to storage, waste compositions reported by the producers are verified and the wastes are segregated into 17 categories as follows:

A-1 Concentrated sulfuric acid solutions with heavy metals

A-2 Concentrated mixed acids with heavy metals

A-3	Dilute acid solutions containing hexavalent chromium and/or other oxidants
A-4	Dilute acid solutions containing heavy metals but no hexavalent chromium or ammonia
A-5	Dilute acid solutions containing heavy metals and ammonium salts
A-6	Acidic nitrate solutions containing heavy metals
A-7	Acidic wastes with hazardous metals except Cr^{+6}
B-1	Alkaline solutions containing cyanides
B-2	Alkaline solutions containing sulfides
B-3	Concentrated alkaline solutions containing no sulfide nor cyanide
B-4	Miscellaneous alkaline solutions containing contaminants other than hazardous metals
B-5	Alkaline solutions containing hazardous metals
C-1	Combustible organic sludges, solids, and liquids
C-2	Sludges, slurries, and solids containing cyanides
C-3	Sludges, slurries, and solids containing hexavalent chromium
C-4	Inorganic sludges, slurries, solids containing no hexavalent chromium nor cyanide
C-5	Wastewater contaminated with high concentrations or organic substances
C-6	Organic contaminated solids

Estimated volume and composition data are given in Appendix G.

Segregation of the wastes serves several necessary and useful functions. Characterization and segregation according to chemical compatability is necessary for safe operation of the plant. For example, acid wastes when combined with cyanide-containing wastes release extremely toxic hydrogen cyanide gas. Segregation and storage permits acquisition of a sufficient inventory of a particular type of waste to facilitate processing, making it possible to use reactants present in some of the wastes for neutralizing certain constituents of other wastes. Typical examples include neutralization of alkaline wastes by acid wastes (thereby minimizing the purchase of neutralizing chemicals), counteracting of waste oxidants with waste reductants, and precipitation of toxic heavy metals with waste sulfides.

Wastes received under categories A-7 and B-5 contain approximately 90 percent of the hazardous toxic metals (except Cr^{+6}). These wastes are stored and processed on a campaign basis to isolate the sludge produced. The latter is then transported to a secured landfill for burial.

The waste receiving, segregation, and storage operations are illustrated in Figures 3, 4, 5, 6, and 7. Some equipment is duplicated in order to show the various operations; for example, separate drum unloading stations would not be required for each waste category. Prior to storage, cyanide-free inorganic sludges (Figure 3) receive acid pretreatment to dissolve soluble constituents.

The receiving, segregation, and storage module contains facilities for unloading drums, tank cars, and tank trailers. Pumpable fluids are transferred to storage tanks and solids or sludges, most of which can be incinerated, are stored until both the waste and the container can be fed to the incinerator. Storage capacity is sufficient to hold at least a five day inventory of feed material.

The unloading facility is equipped with catchment basins in case any material is accidentally spilled during the unloading and transfer operation. Work procedures are clearly defined, including those for emergency operations in case of accidents occur. The work areas are equipped with emergency and safety equipment and apparel for employees, including (but not limited to) safety showers, assault masks, independent breathing air masks, chemical and fire resistant clothing, various fire fighting devices, and alarm systems to warn of hazardous conditions in the work areas. In-plant safety devices include systems which can detect erroneous transfers of material and automatically shut down transfer pumps, if necessary.

Ammonia Stripping Module

Although ammonia is not a hazardous material, significant quantities are expected to be present in some hazardous wastes, and disposal of effluents containing substantial concentrations of ammonia is not permitted in many areas.

FIGURE 3

WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE
CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF LIQUID AQUEOUS WASTES

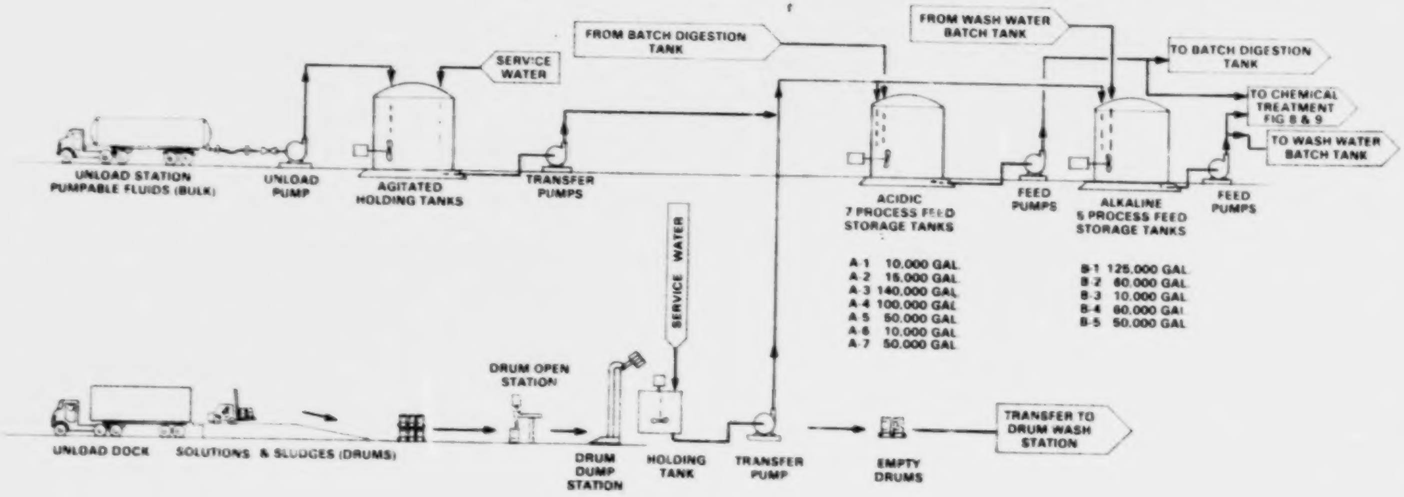

FROM BATCH DIGESTION TANK
FROM WASH WATER BATCH TANK
SERVICE WATER
TO BATCH DIGESTION TANK
TO CHEMICAL TREATMENT FIG 8 & 9
TO WASH WATER BATCH TANK
UNLOAD STATION PUMPABLE FLUIDS (BULK)
UNLOAD PUMP
AGITATED HOLDING TANKS
TRANSFER PUMPS
ACIDIC 7 PROCESS FEED STORAGE TANKS
FEED PUMPS
ALKALINE 5 PROCESS FEED STORAGE TANKS
FEED PUMPS
A-1 10,000 GAL
A-2 15,000 GAL
A-3 140,000 GAL
A-4 100,000 GAL
A-5 50,000 GAL
A-6 10,000 GAL
A-7 50,000 GAL
B-1 125,000 GAL
B-2 60,000 GAL
B-3 10,000 GAL
B-4 60,000 GAL
B-5 50,000 GAL
SERVICE WATER
DRUM OPEN STATION
UNLOAD DOCK
SOLUTIONS & SLUDGES (DRUMS)
DRUM DUMP STATION
HOLDING TANK
TRANSFER PUMP
EMPTY DRUMS
TRANSFER TO DRUM WASH STATION

FIGURE 4

WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF ORGANIC SOLIDS, SLUDGES, SLURRIES, AND SOLUTIONS

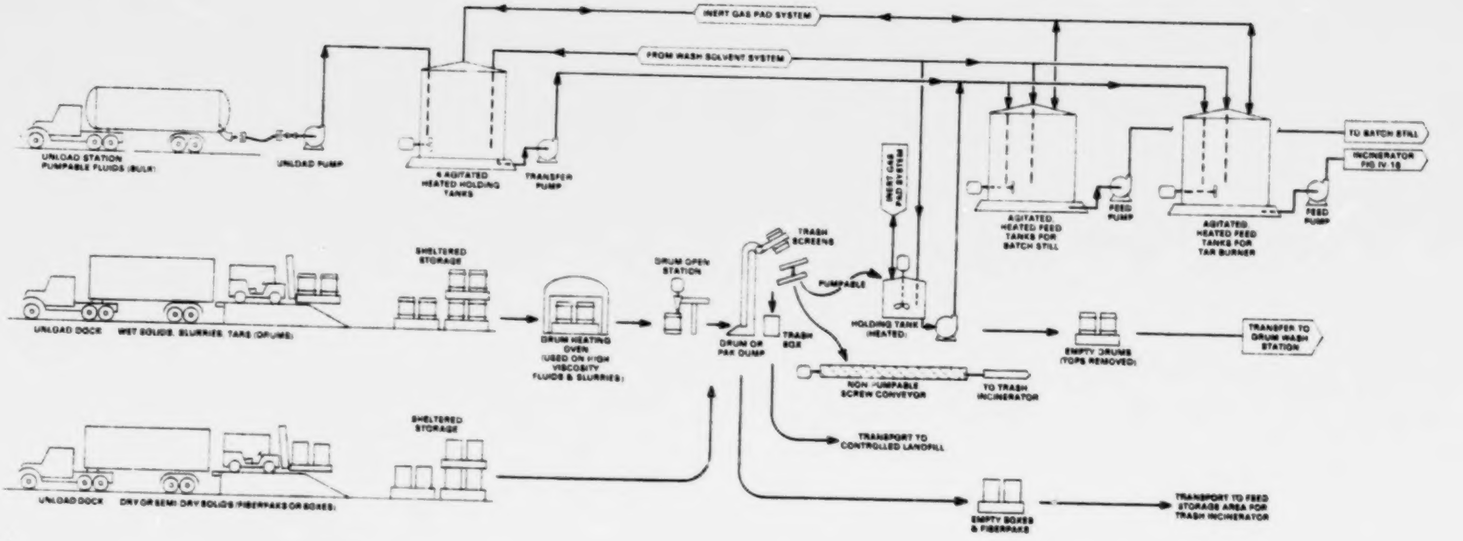
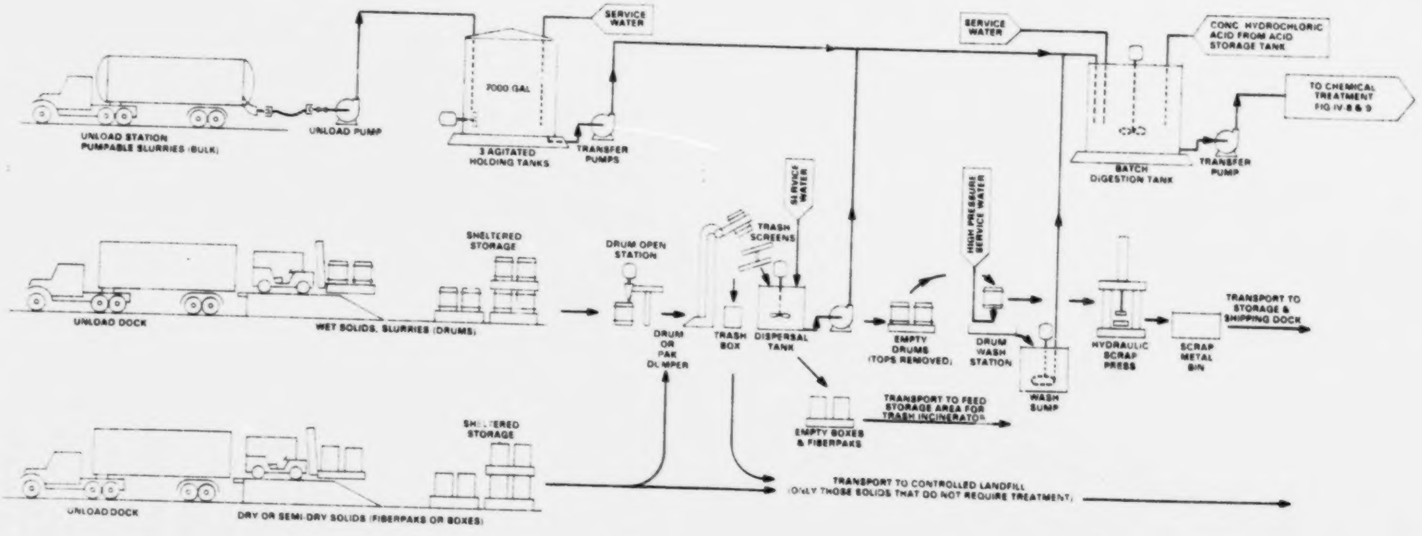

INERT GAS PAD SYSTEM
FROM WASH SOLVENT SYSTEM
UNLOAD STATION
PUMPABLE FLUIDS (BULK)
UNLOAD PUMP
4 AGITATED HEATED HOLDING TANKS
TRANSFER PUMP
INERT GAS PAD SYSTEM
AGITATED, HEATED FEED TANKS FOR BATCH STILL
FEED PUMP
AGITATED, HEATED FEED TANKS FOR TAR BURNER
FEED PUMP
TO BATCH STILL
INCINERATOR FIG IV 18
UNLOAD DOCK
WET SOLIDS, SLURRIES, TARS (DRUMS)
SHELTERED STORAGE
DRUM HEATING OVEN (USED ON HIGH VISCOSITY FLUIDS & SLURRIES)
DRUM OPEN STATION
TRASH SCREENS
DRUM OR PAK DUMP
TRASH BOX
PUMPABLE
HOLDING TANK (HEATED)
EMPTY DRUMS (TOPS REMOVED)
TRANSFER TO DRUM WASH STATION
NON PUMPABLE SCREW CONVEYOR
TO TRASH INCINERATOR
TRANSPORT TO CONTROLLED LANDFILL
UNLOAD DOCK
DRY OR SEMI DRY SOLIDS (FIBERPAKS OR BOXES)
SHELTERED STORAGE
EMPTY BOXES & FIBERPAKS
TRANSPORT TO FEED STORAGE AREA FOR TRASH INCINERATOR

FIGURE 5

WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE
CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE
OF CYANIDE FREE, INORGANIC SOLIDS, SLUDGES, AND SLURRIES



SERVICE WATER
SERVICE WATER
CONC. HYDROCHLORIC ACID FROM ACID STORAGE TANK
7000 GAL
TO CHEMICAL TREATMENT FIG IV 8 & 9
UNLOAD STATION PUMPABLE SLURRIES (BULK)
UNLOAD PUMP
3 AGITATED HOLDING TANKS
TRANSFER PUMPS
BATCH DIGESTION TANK
TRANSFER PUMP
SERVICE WATER
HIGH PRESSURE SERVICE WATER
TRASH SCREENS
SHELTERED STORAGE
DRUM OPEN STATION
TRANSPORT TO STORAGE & SHIPPING DOCK
UNLOAD DOCK
WET SOLIDS, SLURRIES (DRUMS)
DRUM OR PAK DUMPER
TRASH BOX
DISPERSAL TANK
EMPTY DRUMS (TOPS REMOVED)
DRUM WASH STATION
HYDRAULIC SCRAP PRESS
SCRAP METAL BIN
WASH SUMP
EMPTY BOXES & FIBERPAKS
TRANSPORT TO FEED STORAGE AREA FOR TRASH INCINERATOR
SHELTERED STORAGE
TRANSPORT TO CONTROLLED LANDFILL (ONLY THOSE SOLIDS THAT DO NOT REQUIRE TREATMENT)
UNLOAD DOCK
DRY OR SEMI-DRY SOLIDS (FIBERPAKS OR BOXES)

FIGURE 6

WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE
CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE
OF CYANIDE RICH, INORGANIC SOLIDS, SLUDGES, AND SLURRIES

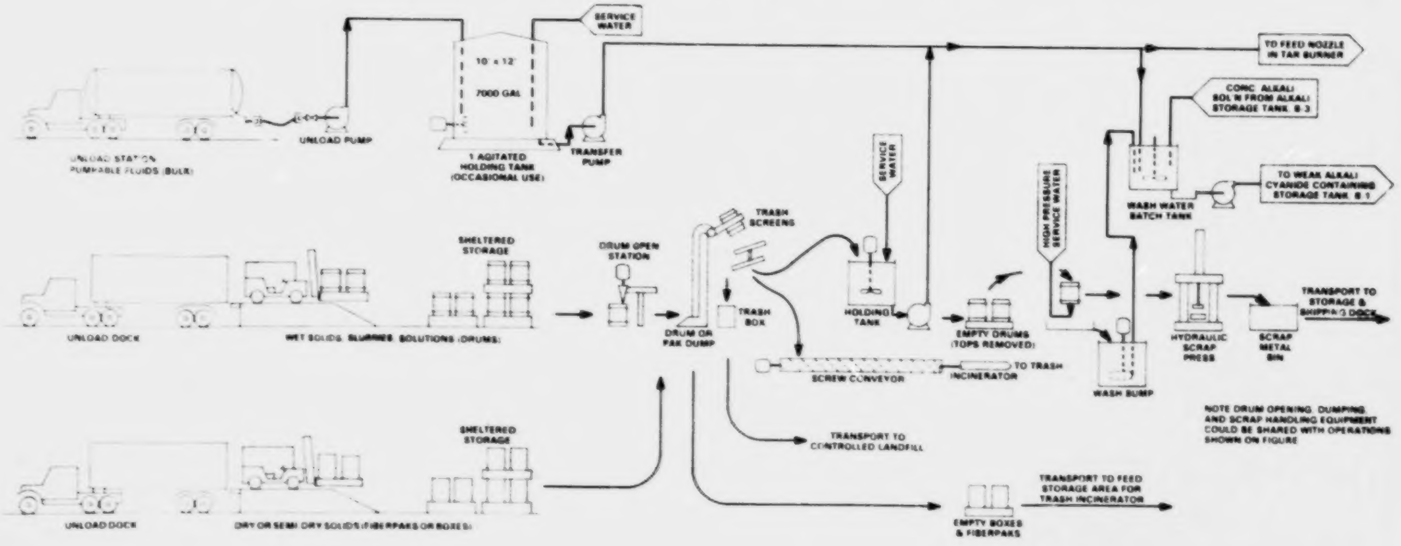
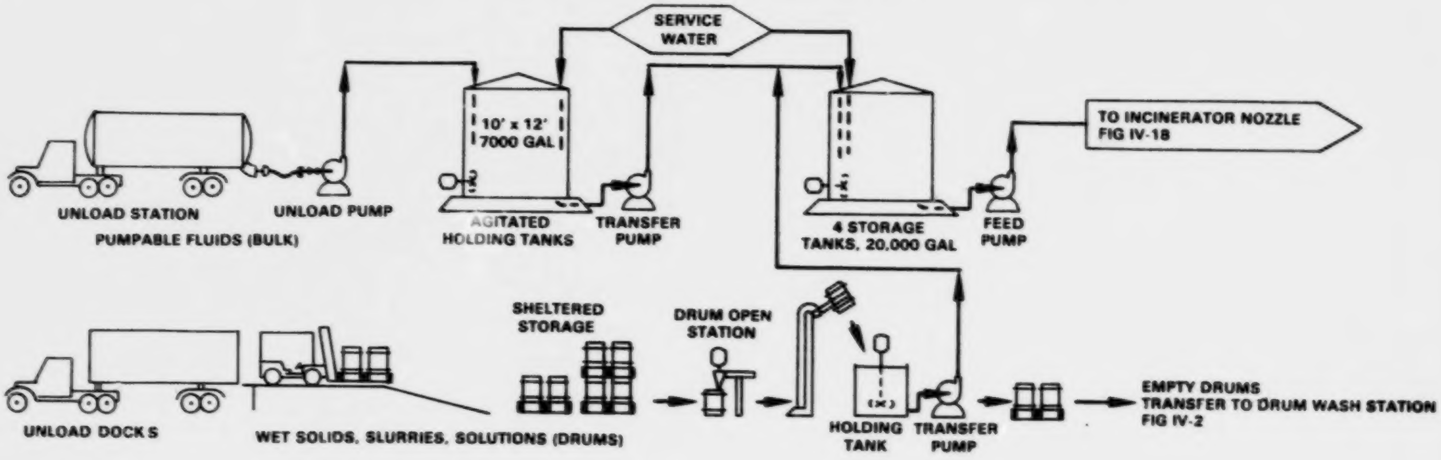

UNLOAD STATION
PUMPABLE FLUIDS (BULK)
UNLOAD PUMP
10' x 12'
7000 GAL
1 AGITATED
HOLDING TANK
(OCCASIONAL USE)
SERVICE WATER
TRANSFER PUMP
TO FEED NOZZLE
IN TAR BURNER
CONC. ALKALI
SOL'N FROM ALKALI
STORAGE TANK B-3
TO WEAK ALKALI
CYANIDE CONTAINING
STORAGE TANK B-1
WASH WATER
BATCH TANK
UNLOAD DOCK
WET SOLIDS, SLURRIES, SOLUTIONS (DRUMS)
SHELTERED
STORAGE
DRUM OPEN
STATION
DRUM OR
PAK DUMP
TRASH
SCREENS
TRASH
BOX
SERVICE
WATER
HOLDING
TANK
EMPTY DRUMS
(TOPS REMOVED)
HIGH PRESSURE
SERVICE WATER
WASH SUMP
HYDRAULIC
SCRAP
PRESS
SCRAP
METAL
BIN
TRANSPORT TO
STORAGE &
SHIPPING DOCK
SCREW CONVEYOR
TO TRASH
INCINERATOR
NOTE DRUM OPENING, DUMPING,
AND SCRAP HANDLING EQUIPMENT
COULD BE SHARED WITH OPERATIONS
SHOWN ON FIGURE
TRANSPORT TO
CONTROLLED LANDFILL
UNLOAD DOCK
DRY OR SEMI DRY SOLIDS (FIBERPAKS OR BOXES)
SHELTERED
STORAGE
EMPTY BOXES
& FIBERPAKS
TRANSPORT TO FEED
STORAGE AREA FOR
TRASH INCINERATOR

FIGURE 7

WASTE RECEIVING, SEGREGATION, AND STORAGE MODULE
CONCEPTUAL FLOW SCHEMATIC FOR C-5 AQUEOUS
ORGANIC CONTAINING-WASTE STREAMS


SERVICE WATER
10' x 12'
7000 GAL
TO INCINERATOR NOZZLE
FIG IV-18
UNLOAD STATION
PUMPABLE FLUIDS (BULK)
UNLOAD PUMP
AGITATED HOLDING TANKS
TRANSFER PUMP
4 STORAGE TANKS, 20,000 GAL
FEED PUMP
SHELTERED STORAGE
DRUM OPEN STATION
UNLOAD DOCKS
WET SOLIDS, SLURRIES, SOLUTIONS (DRUMS)
HOLDING TANK
TRANSFER PUMP
EMPTY DRUMS
TRANSFER TO DRUM WASH STATION
FIG IV-2

The stripper illustrated in Figure 8 removes ammonia by taking advantage of its volatility at high temperatures and pH. Ammonia is transferred from the wastewater to the stripper distillate (or "overheads") and the remaining processed wastewater ("bottoms") is routed to the chemical treatment module. It is anticipated that from 5-20 percent of the feed wastewater will be evaporated in this step.

The distillate from the steam stripper is a concentrated aqueous ammonia stream which can be reclaimed for fertilizer or industrial use. It is not anticipated that a significant profit can be derived from the recovered ammonia since this material is readily available in most areas of the country at low cost. One possible alternative would be barging and ocean disposal in low productivity areas with precautions to prevent over enrichment.

Chemical Treatment Module

The chemical treatment module combines several functions including oxidation, reduction, neutralization, and precipitation. Wastes containing oxidants, principally Cr^{+6}, are treated with sulfur dioxide to reduce the oxidants to less noxious materials (e.g., $Cr^{\pm 6}$ to Cr^{+3}). Reduction with sulfur dioxide is the method most commonly used by large plating plants and was selected for use in the model treatment facility, but other reductants such as sulfite salts and ferrous sulfate may be used if available and economically feasible.

Reduction, as illustrated in Figure 9, is carried out in acid solution in the pH range 2.0-3.0. Under these conditions the reactions which occur are:

$$\underset{\text{Sulfur Dioxide}}{SO_2} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\text{Sulfurous Acid}}{H_2SO_3}$$

$$\underset{\text{Chromic Acid }(Cr^{+6})}{2\ C_2O_3} + \underset{\text{Sulfurous Acid}}{3\ H_2SO_3} \rightarrow \underset{\text{Chromic Sulfate }(Cr^{+3})}{Cr_2(SO_4)_3} + \underset{\text{Water}}{3H_2O}$$

The approximate chemical usage is one pound of SO_2 per pound of chromic acid.

Water containing cyanide may be treated by a variety of methods to convert the cyanide to less toxic substances. Oxidation may be achieved with chlorine, hypoclorites, ozone, peroxide, and

FIGURE 8

CONCEPTUAL FLOW SCHEMATIC OF AMMONIA STRIPPER MODULE

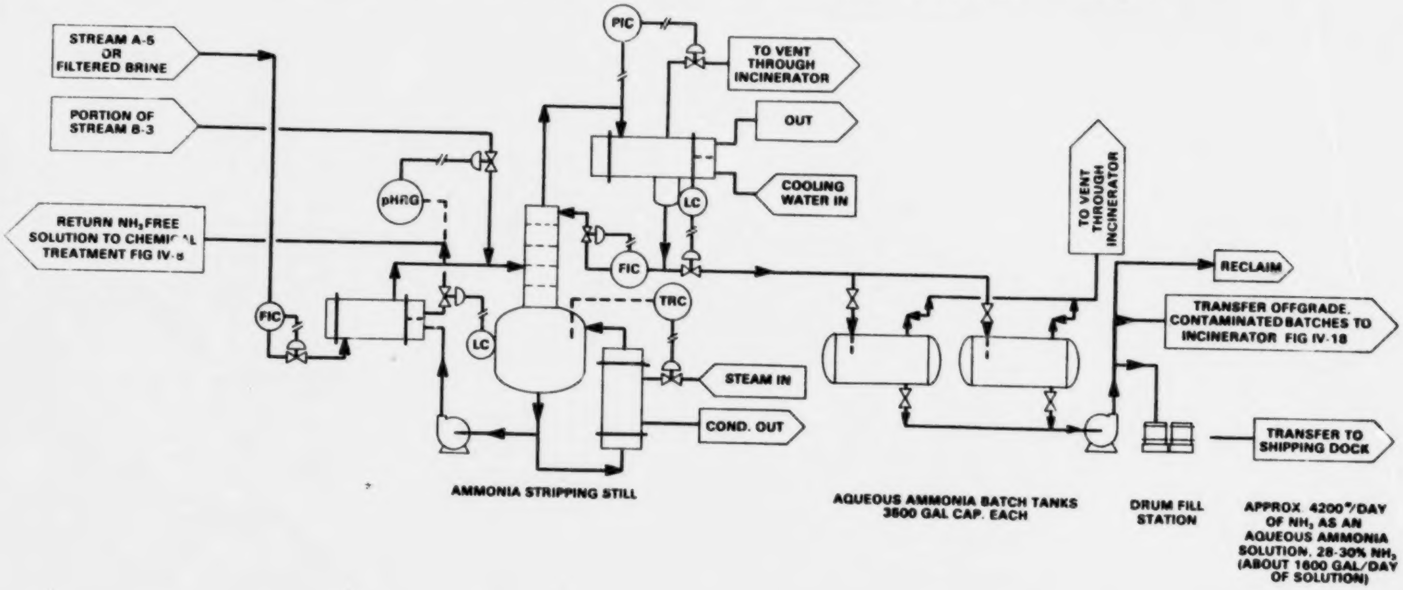
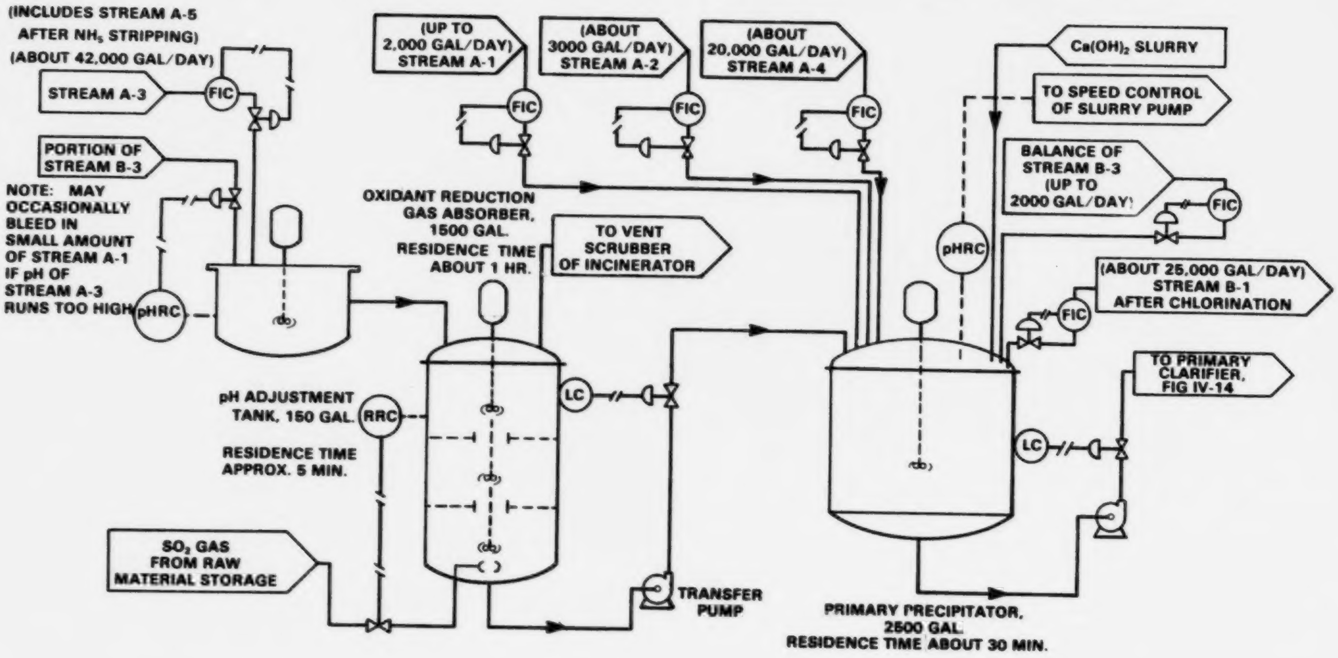

STREAM A-5
OR
FILTERED BRINE
PORTION OF
STREAM B-3
RETURN NH$_3$ FREE
SOLUTION TO CHEMICAL
TREATMENT FIG IV-8
pHRC
FIC
LC
PIC
TO VENT
THROUGH
INCINERATOR
OUT
COOLING
WATER IN
LC
FIC
TRC
STEAM IN
COND. OUT
AMMONIA STRIPPING STILL
TO VENT
THROUGH
INCINERATOR
AQUEOUS AMMONIA BATCH TANKS
3500 GAL CAP. EACH
RECLAIM
TRANSFER OFFGRADE,
CONTAMINATED BATCHES TO
INCINERATOR FIG IV-18
DRUM FILL
STATION
TRANSFER TO
SHIPPING DOCK
APPROX. 4200#/DAY
OF NH$_3$ AS AN
AQUEOUS AMMONIA
SOLUTION, 28-30% NH$_3$
(ABOUT 1600 GAL/DAY
OF SOLUTION)

FIGURE 9

CHEMICAL TREATMENT MODULE
CONCEPTUAL FLOW SCHEMATIC FOR REDUCTION AND PRIMARY PRECIPITATION


(INCLUDES STREAM A-5
AFTER NH$_3$ STRIPPING)
(ABOUT 42,000 GAL/DAY)
STREAM A-3
FIC
PORTION OF STREAM B-3
NOTE: MAY OCCASIONALLY BLEED IN SMALL AMOUNT OF STREAM A-1 IF pH OF STREAM A-3 RUNS TOO HIGH
pHRC
(UP TO 2,000 GAL/DAY) STREAM A-1
FIC
(ABOUT 3000 GAL/DAY) STREAM A-2
FIC
(ABOUT 20,000 GAL/DAY) STREAM A-4
FIC
OXIDANT REDUCTION GAS ABSORBER, 1500 GAL.
RESIDENCE TIME ABOUT 1 HR.
TO VENT SCRUBBER OF INCINERATOR
pH ADJUSTMENT TANK, 150 GAL.
RRC
RESIDENCE TIME APPROX. 5 MIN.
LC
SO$_2$ GAS FROM RAW MATERIAL STORAGE
TRANSFER PUMP
Ca(OH)$_2$ SLURRY
TO SPEED CONTROL OF SLURRY PUMP
BALANCE OF STREAM B-3 (UP TO 2000 GAL/DAY)
FIC
pHRC
(ABOUT 25,000 GAL/DAY) STREAM B-1 AFTER CHLORINATION
FIC
TO PRIMARY CLARIFIER, FIG IV-14
LC
PRIMARY PRECIPITATOR, 2500 GAL.
RESIDENCE TIME ABOUT 30 MIN.

other agents. The method most commonly employed on a large scale, and the one selected for the model processing facility, is oxidation by chlorine. Wastes containing cyanides are treated under alkaline conditions with chlorine to convert the cyanides to cyanates according to the following reaction:

$NaCN$	+	Cl_2	+	$2NaOH$	→	$NaCNO$	+	$2NaCl$	+	H_2O
Sodium Cyanide		Chlorine		Sodium Hydroxide		Sodium Cyanate		Sodium Chloride		Water

The conversion of cyanide to cyanate is a rapid reaction, requiring only a few minutes to complete. The approximate chemical usage is 2.5 pounds of chlorine per pound of cyanide. Since cyanate is about a thousand times less toxic than cyanide, it may be acceptable to dispose of cyanates by ocean disposal off the continental shelf or by deep well injection.

If further treatment of cyanates is necessary, chlorine can be employed to convert the cyanate to carbon dioxide (or carbonates in alkaline solution), nitrogen, and water as follows:

$2\ Na\ CNO$	+	$4\ NaOH$	+	$3Cl_2$	→	$6\ NaCl$	+	$2CO_2$	+	N_2	+	H_2O
Sodium Cyanate		Sodium Hydroxide		Chlorine		Sodium Chloride		Carbon Dioxide		Nitrogen		Water

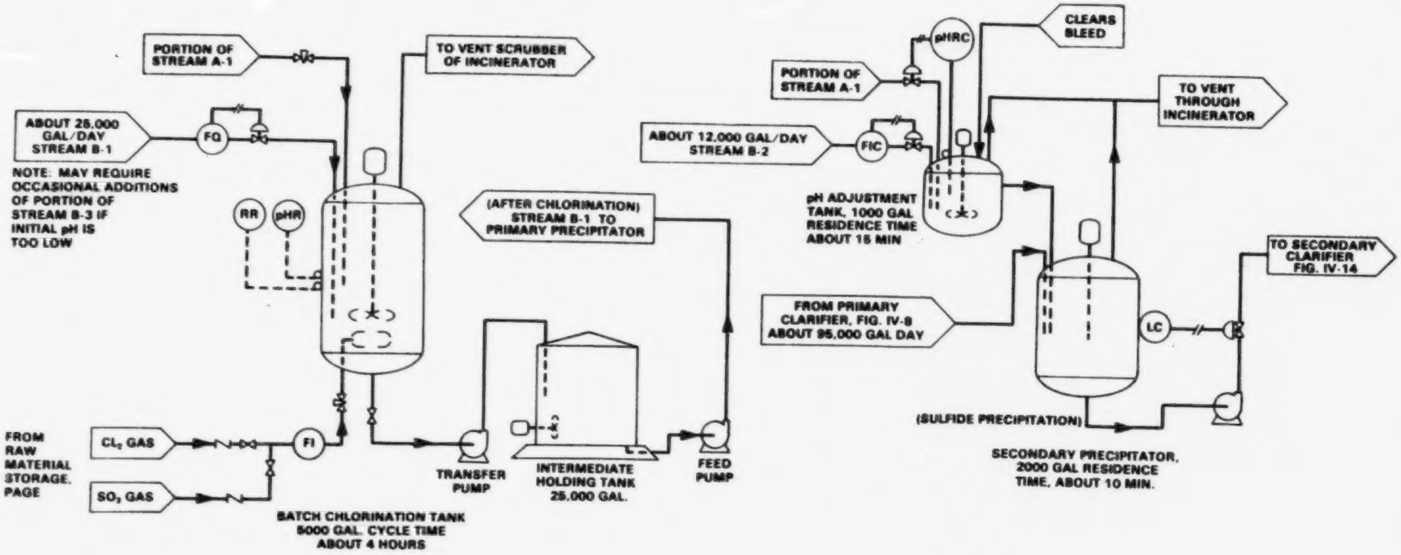
The overall reaction of cyanide with chlorine is as follows:

$2\ NaCN$	+	$5Cl_2$	+	$12\ NaOH$	→	$10\ NaCl$	+	$2Na_2CO_3$	+	N_2	+	$6H_2O$
Sodium Cyanide		Chlorine		Sodium Hydroxide		Sodium Chloride		Sodium Carbonate		Nitrogen		Water

Adequate mixing is required to obtain reasonable reaction rates and the overall reaction is fairly slow, requiring hours for complete destruction of the cyanide, particularly if heavy metal cyanide complexes are present. Chemical usage for the overall reaction is approximately four pounds of chlorine and nine pounds of sodium hydroxide per pound of cyanide. The flow schematic for cyanide oxidation is illustrated in Figure 10.

FIGURE 10

CHEMICAL TREATMENT MODULE
CONCEPTUAL FLOW SCHEMATIC FOR OXIDATION AND SECONDARY PRECIPITATION


PORTION OF STREAM A-1
TO VENT SCRUBBER OF INCINERATOR
ABOUT 25,000 GAL/DAY STREAM B-1
FQ
NOTE: MAY REQUIRE OCCASIONAL ADDITIONS OF PORTION OF STREAM B-3 IF INITIAL pH IS TOO LOW
RR
pHR
(AFTER CHLORINATION) STREAM B-1 TO PRIMARY PRECIPITATOR
FROM RAW MATERIAL STORAGE, PAGE
Cl_2 GAS
SO_2 GAS
FI
TRANSFER PUMP
INTERMEDIATE HOLDING TANK 25,000 GAL.
FEED PUMP
BATCH CHLORINATION TANK 5000 GAL. CYCLE TIME ABOUT 4 HOURS
CLEARS BLEED
pHRC
PORTION OF STREAM A-1
TO VENT THROUGH INCINERATOR
ABOUT 12,000 GAL/DAY STREAM B-2
FIC
pH ADJUSTMENT TANK, 1000 GAL RESIDENCE TIME ABOUT 15 MIN
TO SECONDARY CLARIFIER FIG. IV-14
FROM PRIMARY CLARIFIER, FIG. IV-8 ABOUT 95,000 GAL DAY
LC
(SULFIDE PRECIPITATION)
SECONDARY PRECIPITATOR, 2000 GAL RESIDENCE TIME, ABOUT 10 MIN.

Although nitrate is not a hazardous substance, pollution control regulations restrict its disposal and treatment and disposal of wastewater containing substantial amounts of nitrate may be difficult or expensive in some areas. Moderate amounts of nitrates can be reduced in the chemical treatment module but large quantities of ferrous salts are required.[86] A separate storage tank has been designated for wastes containing large amounts of nitrate to permit their processing on a campaign basis. It is assumed that ocean disposal of brines containing nitrate salts will be permitted in low productivity areas of the ocean since the alternative of land burial is less desirable due to potential grounwater contamination. The cost of transporting these brines will be greater than for low-nitrate brines which can be disposed near the shore, since ocean areas of low productivity are located much farther from the coastline.

Effluents from the oxidation/reduction steps are blended with other waste streams as indicated in Figure 9. The neutralization operation results in the precipitation of heavy metal hydroxides or hydrous oxides and calcium sulfate. Approximately 95 percent of the sludge produced will not contain significant amounts of hazardous heavy metals because such wastes are segregated. Some of the sludge will contain organic matter, thus requiring incineration prior to disposal in a conventional landfill; however, the small percentage of sludges containing substantial quantities of sulfides and/or relatively volatile heavy metals (e.g., arsenic, mercury) should not be incinerated because of potential air pollution problems. Since the heavy hydroxide precipitation occurs prior to sulfide precipitation most of the suspended organics will be associated with the metal hydroxide sludges rather than the metal sulfide sludges. The relatively volatile heavy metals happen to be in the hazardous category and therefore sludges containing these metals in addition to hazardous organic substances will be buried in a secured landfill without incineration.

Lime addition to the primary precipitator will be controlled to maintain a pH of about 5. At this pH level the precipitate formed consists largely of ferric hydroxide, aluminum hydroxide, and calcium sulfate, with smaller quantities of other heavy metal hydroxides. After separation of the precipitate in the primary clarifier the supernatant liquid is returned to the secondary precipitator (Figure 10) where sulfide wastes, plus additional sodium sulfide if required, are added to precipitate metal sulfides (at a pH of about 7). A bleed stream of clarified incinerator scrubber water (*clears*) is also fed into the secondary precipitator for treatment. The slurry from the secondary precipitator is then routed to the secondary clarifier.

The chemical treatment module also includes facilities for receiving, storage, and distribution of reagent chemicals. More lime is used than any other chemical; it is purchased in the unslaked form and slaked on-site. Receiving, storage and distribution schematics for lime and polyelectrolyte flocculant are presented in Figure 11. Figures 12 and 13 illustrate the flow schematics for receiving, storage and distribution of nitrogen gas, sulfur dioxide, chlorine, hydrochloric acid, sodium hydroxide, and sodium sulfide.

Nitrogen gas is employed as an inert gas blanket for the vessel and vent systems; chlorine and sulfur dioxide are used for oxidation and reduction reactions; hydrochloric acid is used for leaching sludges and for pH adjustment; sodium hydroxide is used for pH adjustment; and sodium sulfide is used for metal sulfide precipitation.

LIQUID-SOLIDS SEPARATION MODULE

The liquid-solids separation module includes the following equipment:

- A primary clarifier and two vacuum filters for removing and dewatering metal hydroxides, hydrous oxides, and calcium sulfate;
- a secondary clarifier and vacuum filter for removing and dewatering metal sulfide sludges;
- a thickener and vacuum filter for removing and dewatering incinerator ash; and
- three tri-media filters for removing residual particulate matter from the secondary clarifier overflow.

Schematic flow diagrams for these operations are illustrated in Figures 14-17.

Sludges from the clarifiers and thickeners will be filtered, washed to remove soluble salts, and dewatered to about 60 percent moisture prior to disposal. Non-hazardous sludges containing low concentrations of hazardous substances will be collected in a suitable container for shipment to a secured landfill.

The secondary clarifier overflow is directed to the tri-media filters for removal of residual suspended solids. The tri-media filters are illustrated in Figure 11 along with a filtrate holding tank where chlorine is added to oxidize excess sulfide ion in the filtrate. Tri-media filters were selected for the

The chemical treatment module also includes facilities for receiving, storage, and distribution of reagent chemicals. More lime is used than any other chemical; it is purchased in the unslaked form and slaked on-site. Receiving, storage and distribution schematics for lime and polyelectrolyte flocculant are presented in Figure 11. Figures 12 and 13 illustrate the flow schematics for receiving, storage and distribution of nitrogen gas, sulfur dioxide, chlorine, hydrochloric acid, sodium hydroxide, and sodium sulfide.

Nitrogen gas is employed as an inert gas blanket for the vessel and vent systems; chlorine and sulfur dioxide are used for oxidation and reduction reactions; hydrochloric acid is used for leaching sludges and for pH adjustment; sodium hydroxide is used for pH adjustment; and sodium sulfide is used for metal sulfide precipitation.

LIQUID-SOLIDS SEPARATION MODULE

The liquid-solids separation module includes the following equipment:

- A primary clarifier and two vacuum filters for removing and dewatering metal hydroxides, hydrous oxides, and calcium sulfate;
- a secondary clarifier and vacuum filter for removing and dewatering metal sulfide sludges;
- a thickener and vacuum filter for removing and dewatering incinerator ash; and
- three tri-media filters for removing residual particulate matter from the secondary clarifier overflow.

Schematic flow diagrams for these operations are illustrated in Figures 14-17.

Sludges from the clarifiers and thickeners will be filtered, washed to remove soluble salts, and dewatered to about 60 percent moisture prior to disposal. Non-hazardous sludges containing low concentrations of hazardous substances will be collected in a suitable container for shipment to a secured landfill.

The secondary clarifier overflow is directed to the tri-media filters for removal of residual suspended solids. The tri-media filters are illustrated in Figure 11 along with a filtrate holding tank where chlorine is added to oxidize excess sulfide ion in the filtrate. Tri-media filters were selected for the

FIGURE 11

CHEMICAL TREATMENT MODULE
CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE OF LIME AND POLYELECTROLYTE

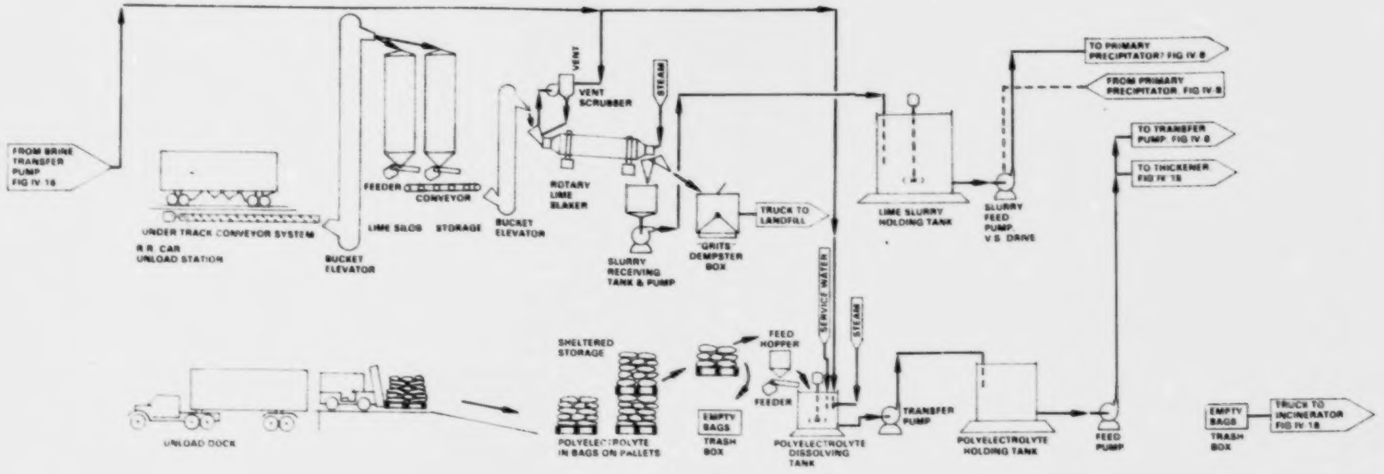

FROM BRINE TRANSFER PUMP FIG IV 16
UNDER TRACK CONVEYOR SYSTEM
R.R. CAR UNLOAD STATION
BUCKET ELEVATOR
FEEDER
CONVEYOR
LIME SILOS
STORAGE
BUCKET ELEVATOR
VENT
VENT SCRUBBER
STEAM
ROTARY LIME SLAKER
SLURRY RECEIVING TANK & PUMP
"GRITS" DEMPSTER BOX
TRUCK TO LANDFILL
LIME SLURRY HOLDING TANK
SLURRY FEED PUMP, V.S. DRIVE
TO PRIMARY PRECIPITATOR? FIG IV 8
FROM PRIMARY PRECIPITATOR FIG IV 8
TO TRANSFER PUMP FIG IV 8
TO THICKENER FIG IV 15
UNLOAD DOCK
SHELTERED STORAGE
POLYELECTROLYTE IN BAGS ON PALLETS
EMPTY BAGS
TRASH BOX
FEED HOPPER
FEEDER
SERVICE WATER
STEAM
POLYELECTROLYTE DISSOLVING TANK
TRANSFER PUMP
POLYELECTROLYTE HOLDING TANK
FEED PUMP
EMPTY BAGS
TRASH BOX
TRUCK TO INCINERATOR FIG IV 18

FIGURE 12

CHEMICAL TREATMENT MODULE
CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE
OF NITROGEN, SULFUR DIOXIDE, AND CHLORINE

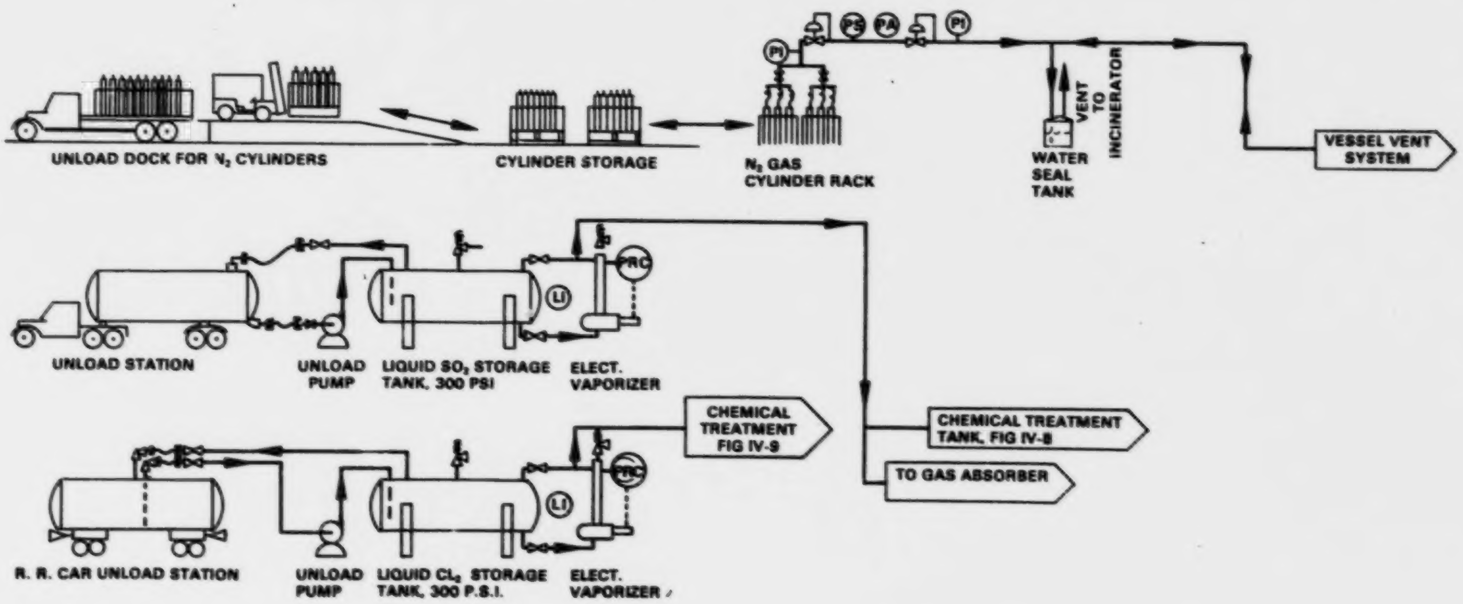

UNLOAD DOCK FOR N_2 CYLINDERS
CYLINDER STORAGE
N_2 GAS CYLINDER RACK
PI
PS
PA
PI
WATER SEAL TANK
VENT TO INCINERATOR
VESSEL VENT SYSTEM
UNLOAD STATION
UNLOAD PUMP
LIQUID SO_2 STORAGE TANK, 300 PSI
LI
PRC
ELECT. VAPORIZER
CHEMICAL TREATMENT TANK, FIG IV-8
TO GAS ABSORBER
CHEMICAL TREATMENT FIG IV-9
R. R. CAR UNLOAD STATION
UNLOAD PUMP
LIQUID Cl_2 STORAGE TANK, 300 P.S.I.
LI
PRC
ELECT. VAPORIZER

FIGURE 13

CHEMICAL TREATMENT MODULE
CONCEPTUAL FLOW SCHEMATIC FOR RECEIVING AND STORAGE
OF HYDROCHLORIC ACID AND SODIUM SULFIDE

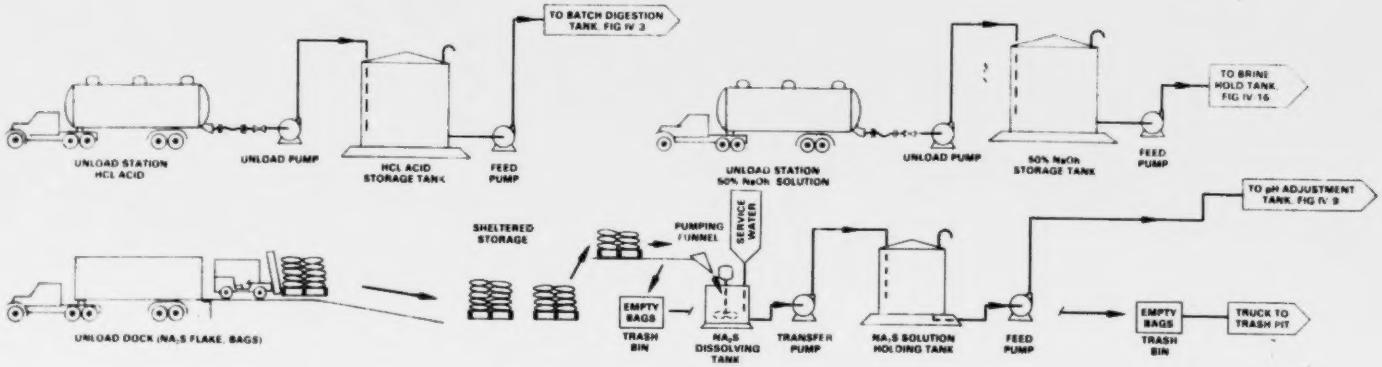

TO BATCH DIGESTION TANK. FIG IV 3
UNLOAD STATION HCL ACID
UNLOAD PUMP
HCL ACID STORAGE TANK
FEED PUMP
UNLOAD STATION 50% NaOh SOLUTION
UNLOAD PUMP
50% NaOh STORAGE TANK
FEED PUMP
TO BRINE HOLD TANK. FIG IV 16
UNLOAD DOCK (NA$_2$S FLAKE, BAGS)
SHELTERED STORAGE
PUMPING FUNNEL
SERVICE WATER
EMPTY BAGS
TRASH BIN
NA$_2$S DISSOLVING TANK
TRANSFER PUMP
NA$_2$S SOLUTION HOLDING TANK
FEED PUMP
TO pH ADJUSTMENT TANK. FIG IV 9
EMPTY BAGS
TRASH BIN
TRUCK TO TRASH PIT

FIGURE 14

LIQUID-SOLIDS SEPARATION MODULE
CONCEPTUAL FLOW SCHEMATIC FOR
PRIMARY CLARIFICATION AND SLUDGE FILTRATION

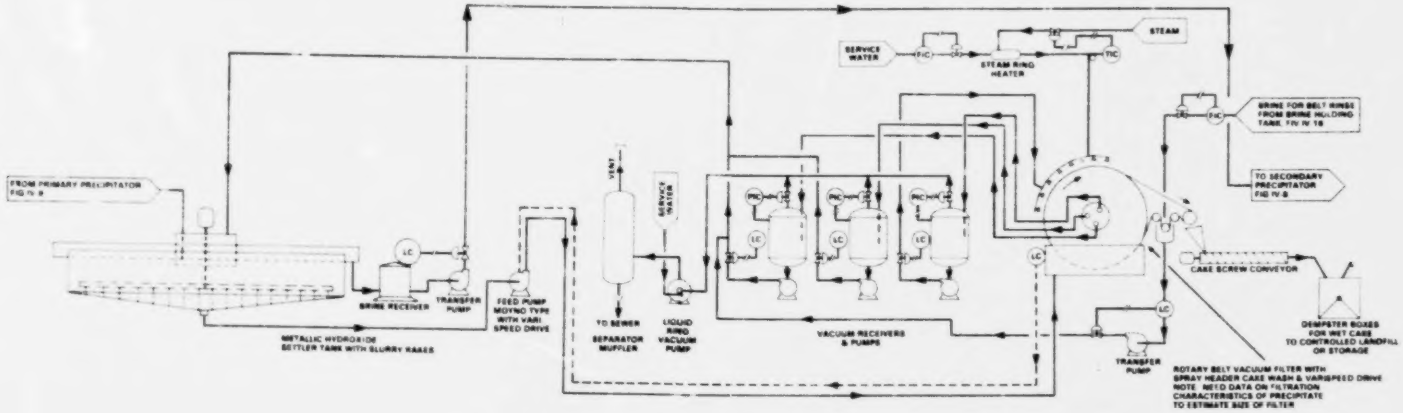

FROM PRIMARY PRECIPITATOR
FIG IV 9
METALLIC HYDROXIDE
SETTLER TANK WITH SLURRY RAKES
LC
BRINE RECEIVER
TRANSFER PUMP
FEED PUMP
MOYNO TYPE
WITH VARI
SPEED DRIVE
VENT
TO SEWER
SEPARATOR
MUFFLER
SERVICE WATER
LIQUID
RING
VACUUM
PUMP
PIC
LC
VACUUM RECEIVERS
& PUMPS
SERVICE WATER
FIC
STEAM RING
HEATER
STEAM
TIC
LC
TRANSFER
PUMP
BRINE FOR BELT RINSE
FROM BRINE HOLDING
TANK FIV IV 18
FIC
TO SECONDARY
PRECIPITATOR
FIG IV 8
CAKE SCREW CONVEYOR
DEMPSTER BOXES
FOR WET CAKE
TO CONTROLLED LANDFILL
OR STORAGE
ROTARY BELT VACUUM FILTER WITH
SPRAY HEADER CAKE WASH & VARISPEED DRIVE
NOTE NEED DATA ON FILTRATION
CHARACTERISTICS OF PRECIPITATE
TO ESTIMATE SIZE OF FILTER

FIGURE 15

LIQUID-SOLIDS SEPARATION MODULE
CONCEPTUAL FLOW DIAGRAM FOR
SECONDARY CLARIFICATION AND SLUDGE FILTRATION

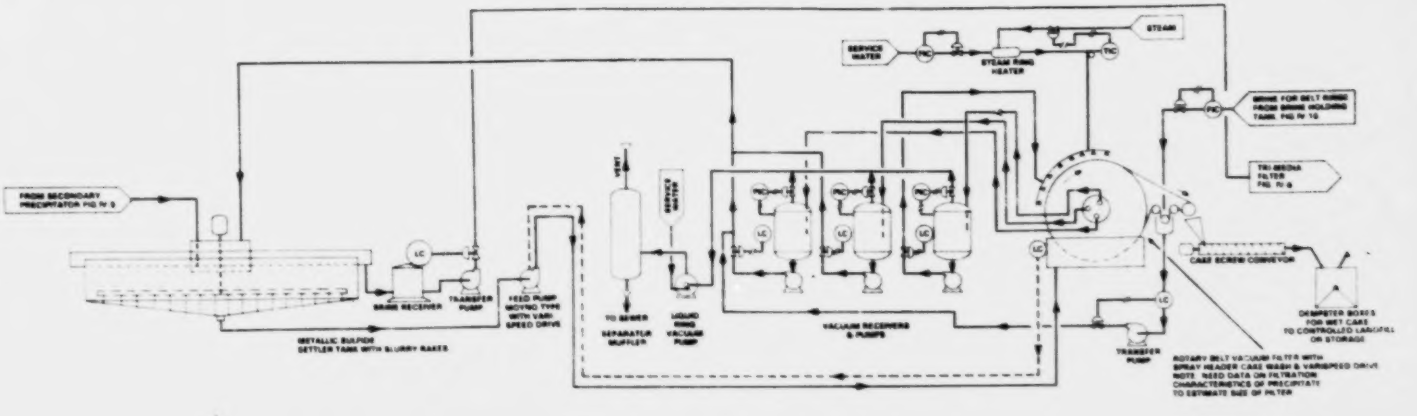
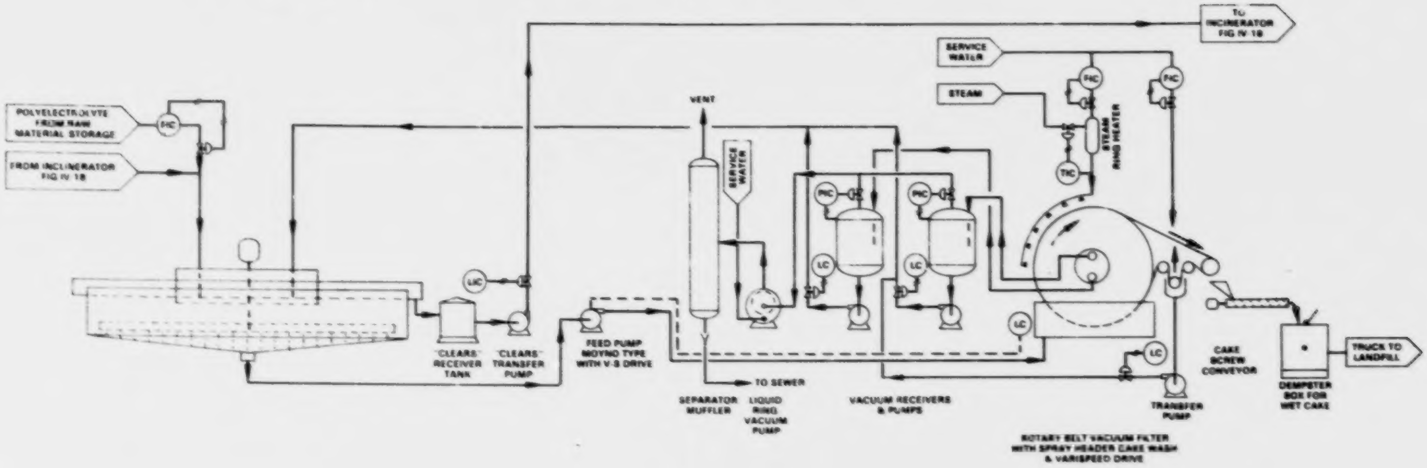

FROM SECONDARY PRECIPITATOR FIG IV 9
LC
BRINE RECEIVER
TRANSFER PUMP
FEED PUMP MOYNO TYPE WITH VARI SPEED DRIVE
METALLIC SULFIDE SETTLER TANK WITH SLURRY RAKES
VENT
TO SEWER
SEPARATOR MUFFLER
SERVICE WATER
LIQUID RING VACUUM PUMP
PIC
LC
VACUUM RECEIVERS & PUMPS
SERVICE WATER
PIC
STEAM RING HEATER
STEAM
TIC
BRINE FOR BELT RINSE FROM BRINE HOLDING TANK FIG IV 10
PIC
TRI-MEDIA FILTER FIG IV 6
CAKE SCREW CONVEYOR
DEMPSTER BOXES FOR WET CAKE TO CONTROLLED LANDFILL OR STORAGE
TRANSFER PUMP
ROTARY BELT VACUUM FILTER WITH SPRAY HEADER CAKE WASH & VARISPEED DRIVE
NOTE: NEED DATA ON FILTRATION CHARACTERISTICS OF PRECIPITATE TO ESTIMATE SIZE OF FILTER

FIGURE 16

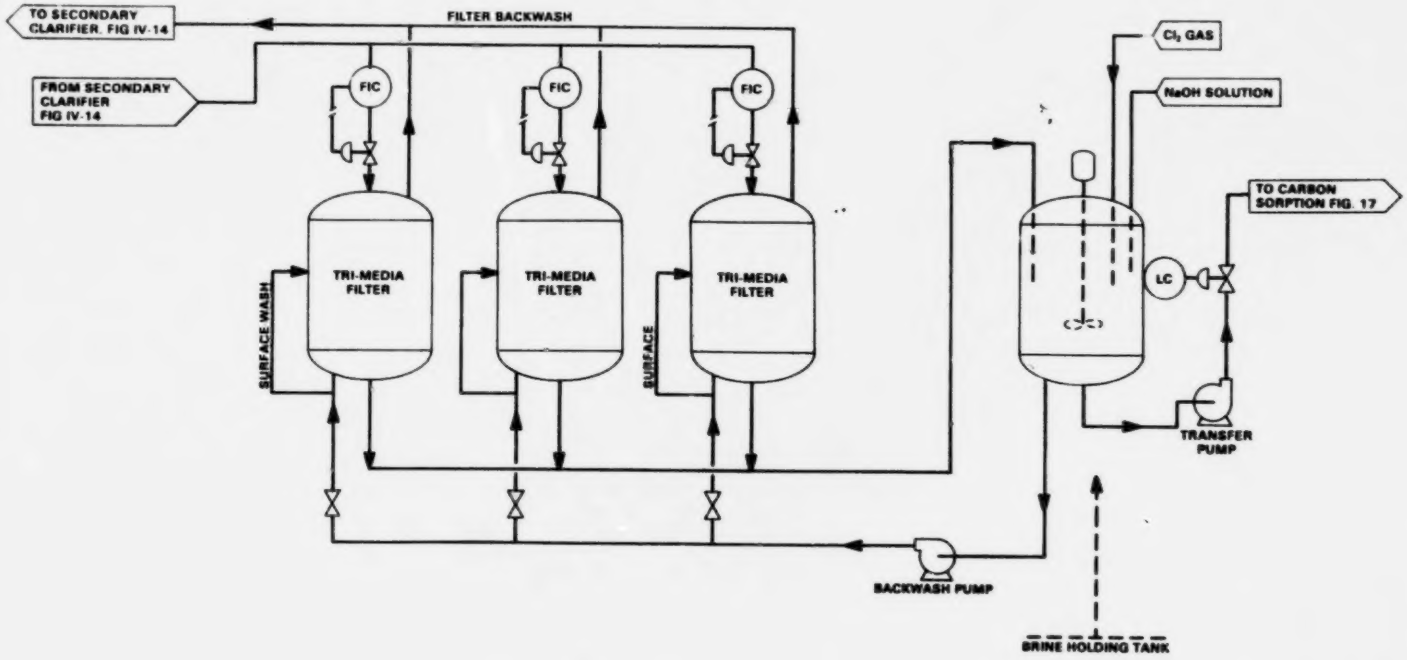
LIQUID-SOLIDS SEPARATION MODULE
CONCEPTUAL FLOW SCHEMATIC FOR CLARIFICATION
OF INCINERATOR SCRUBBER WATER AND FILTRATION OF ASH SLUDGE



POLYELECTROLYTE FROM RAW MATERIAL STORAGE
FIC
FROM INCLINERATOR FIG IV 18
LIC
"CLEARS" RECEIVER TANK
"CLEARS" TRANSFER PUMP
FEED PUMP MOYNO TYPE WITH V-S DRIVE
VENT
SERVICE WATER
SEPARATOR MUFFLER
LIQUID RING VACUUM PUMP
TO SEWER
PIC
LC
PIC
LC
VACUUM RECEIVERS & PUMPS
TO INCINERATOR FIG IV 18
SERVICE WATER
STEAM
FIC
FIC
TIC
STEAM RING HEATER
LC
LC
TRANSFER PUMP
ROTARY BELT VACUUM FILTER WITH SPRAY HEADER CAKE WASH & VARISPEED DRIVE
CAKE SCREW CONVEYOR
DEMPSTER BOX FOR WET CAKE
TRUCK TO LANDFILL

FIGURE 17

LIQUID-SOLIDS SEPARATION MODULE
CONCEPTUAL FLOW SCHEMATIC FOR BRINE FILTRATION


TO SECONDARY CLARIFIER, FIG IV-14
FILTER BACKWASH
FROM SECONDARY CLARIFIER FIG IV-14
FIC
FIC
FIC
TRI-MEDIA FILTER
TRI-MEDIA FILTER
TRI-MEDIA FILTER
SURFACE WASH
SURFACE
Cl$_2$ GAS
NaOH SOLUTION
TO CARBON SORPTION FIG. 17
LC
TRANSFER PUMP
BACKWASH PUMP
BRINE HOLDING TANK

liquid filtration operation because this type of filter is much more efficient than other types.[58] Tri-media filters are similar to rapid sand filters but contain three different layers of granular filter media; the top layer is coarse grade anthracite coal, the center layer is medium grade sand, and the bottom layer is fine grade garnet sand. Filtration is accomplished in the direction of coarse-to-fine, permitting higher particulate loadings in the filter media. In addition, filtrate clarity achieved with a tri-media filter is generally superior to that of a single or dual-media filter. Attaining a high degree of filtrate clarity is important because residual hazardous metals in the liquid are largely in the particulate form.

Carbon Sorption Module

The carbon sorption module (Figure 18) removes soluble organic substances from the waste brine. The carbon sorption columns are designed to operate upflow in series or in parallel to achieve the desired degree of removal. Upflow operation permits semi-continuous removal of exhausted carbon from the beds, thus minimizing the inventory of carbon required. Exhausted carbon is removed from the beds for thermal regeneration in a furnace. The freshly regenerated carbon from the furnace is subsequently quenched in water and transferred to a storage tank prior to use in the packed columns. Gaseous products from the regeneration furnace are routed to the incinerator to assure complete destruction of residual organic vapors.

Incinerator Module

A rotary kiln incinerator was selected in preference to other types of incinerators because of its versatility.[19] The rotary kiln incinerator is highly efficient when applied to solids, liquids, sludges, and tars because of its ability to thoroughly mix unburned waste and oxygen as it revolves. A conceptual flow schematic of the incineration system illustrating the various features of the incinerator and auxiliary equipment is given in Figure 19. Pollution control features include a spray quench chamber, a Venturi scrubber, and a demister, all of which are designed to cool off-gases and remove particulate matter and certain chemical constituents (e.g., HCl and SO_2) from the off-gases. Wastewater and ash are routed as a slurry to a thickener (Figure 16) where the ash is removed and clarified water (*clears*) is returned to the incineration system. As indicated earlier a bleed stream is removed from the *clears* for treatment and disposal.

Combustible wastes are classified according to anticipated heat generation and burning rates before incineration. The rotary kiln can accept metal drums containing solid wastes that cannot

FIGURE 18

CONCEPTUAL FLOW SCHEMATIC FOR CARBON SORPTION MODULE

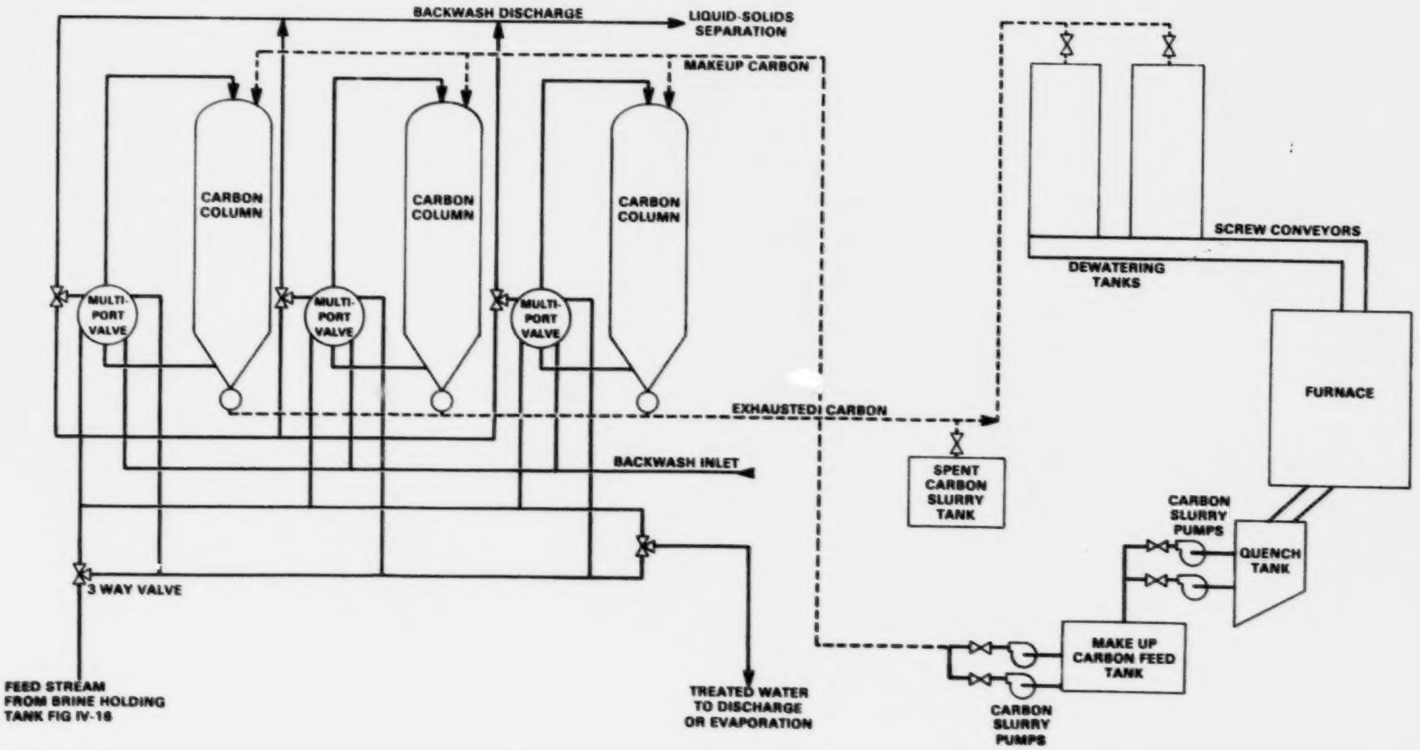
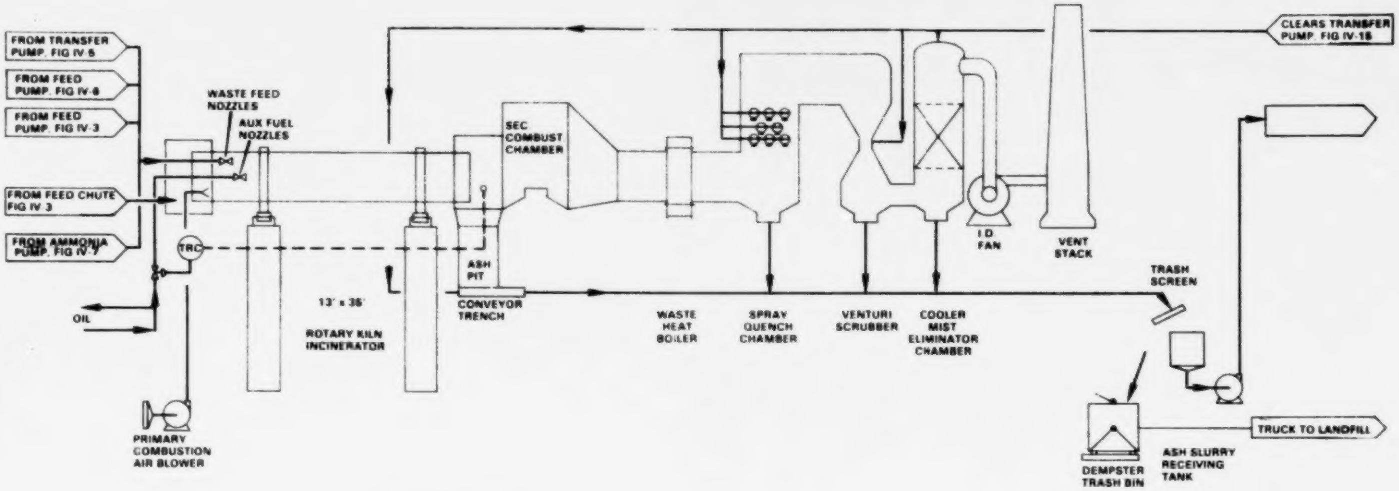

BACKWASH DISCHARGE
LIQUID-SOLIDS SEPARATION
MAKEUP CARBON
CARBON COLUMN
CARBON COLUMN
CARBON COLUMN
MULTI-PORT VALVE
MULTI-PORT VALVE
MULTI-PORT VALVE
EXHAUSTED CARBON
BACKWASH INLET
3 WAY VALVE
FEED STREAM FROM BRINE HOLDING TANK FIG IV-16
TREATED WATER TO DISCHARGE OR EVAPORATION
DEWATERING TANKS
SCREW CONVEYORS
FURNACE
SPENT CARBON SLURRY TANK
CARBON SLURRY PUMPS
QUENCH TANK
MAKE UP CARBON FEED TANK
CARBON SLURRY PUMPS

FIGURE 19

INCINERATION MODULE
CONCEPTUAL FLOW SCHEMATIC OF INCINERATION SYSTEM


FROM TRANSFER PUMP, FIG IV-5
FROM FEED PUMP, FIG IV-6
FROM FEED PUMP, FIG IV-3
FROM FEED CHUTE FIG IV-3
FROM AMMONIA PUMP, FIG IV-7
WASTE FEED NOZZLES
AUX FUEL NOZZLES
TRC
OIL
PRIMARY COMBUSTION AIR BLOWER
13' x 35'
ROTARY KILN INCINERATOR
ASH PIT
CONVEYOR TRENCH
SEC COMBUST CHAMBER
WASTE HEAT BOILER
SPRAY QUENCH CHAMBER
VENTURI SCRUBBER
COOLER MIST ELIMINATOR CHAMBER
I.D. FAN
VENT STACK
CLEARS TRANSFER PUMP, FIG IV-15
TRASH SCREEN
DEMPSTER TRASH BIN
ASH SLURRY RECEIVING TANK
TRUCK TO LANDFILL

be readily removed. Aqueous waste streams contaminated with relatively high concentrations of soluble organics will also be processed in the incinerator. Supplementary fuel will be supplied to complete incineration of these aqueous-organic waste streams. The incinerator has a design capacity of 40 million BTU/hr with an estimated HCl production of 200 lbs/hr. Incinerator residue is expected to be produced an average rate of 3,000 lbs/day.

Evaporation Module

A submerged combustion evaporator was selected for use in reducing the brine effluents to a salt cake (see Figure 20). This type of evaporator is well adapted for use in evaporating strong brine solutions. When brines are evaporated from 10 percent salt up to about 50 percent salt, a salt cake will form on cooling. The salt cake may be disposed to an arid region landfill, or reclaimed for use in road salting, or disposed to the ocean. Evaporation would normally be used in processing facilities located far from the ocean or deep well injection sites, in which case the total cost of evaporation of the brine and transportation and disposal of the salt cake is less than the cost of transportation and disposal of the brine.

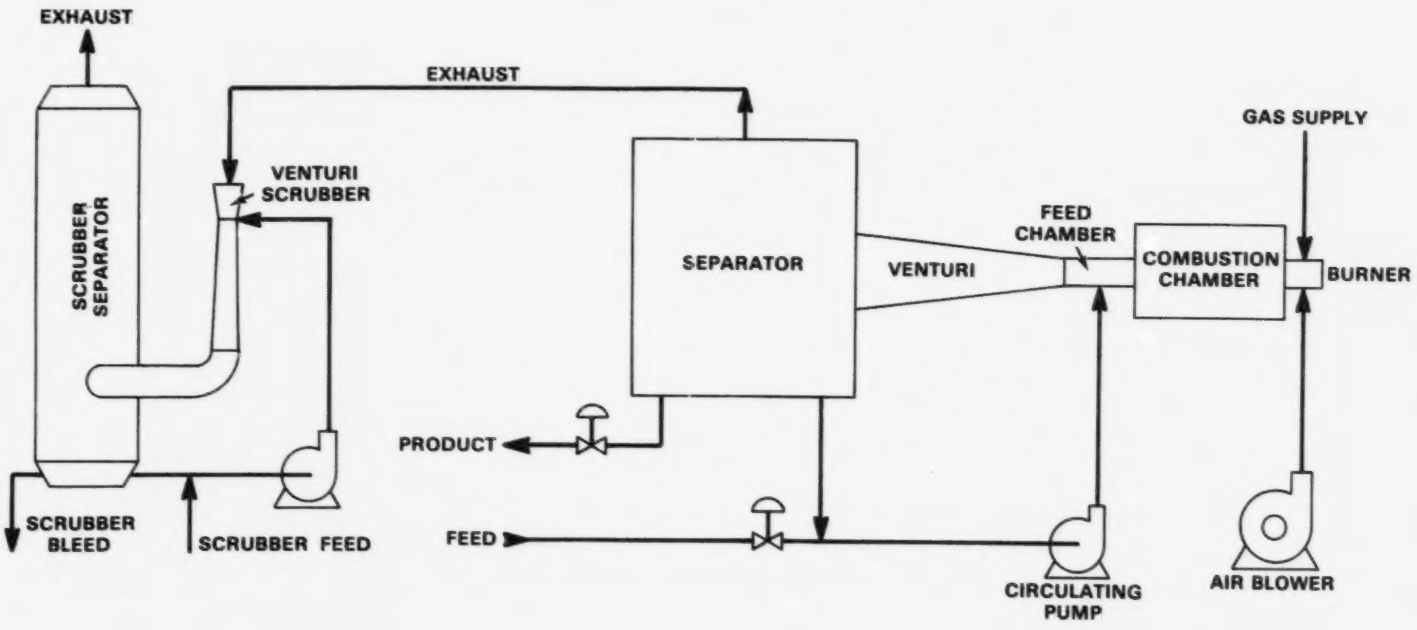
In operation of the submerged combustion evaporator, feed solution is introduced to the circulation system and pumped to the feed chamber to be atomized in the combustion chamber. The combustion products and the solution are mixed in the venturi where evaporation takes place. Droplets of concentrated solution are separated from gases in the separator and a part of the concentrated solution is recycled. Effluent gases from the separator are cleaned in the modified venturi scrubber which is fed with weak liquor. Scrubbed gases are separated from the liquor in the separator section and discharged. The condensate from the evaporator will be of suitable quality for disposal to surface receiving waters.

LANDFILLS

Two types of landfills for disposal of solid wastes are included in the modular flow diagram in Figure 2. A conventional landfill will be located near the processing facility to minimize transportation costs. Solid wastes placed here will not contain significant levels of hazardous substances. Secured landfills, which will be located in areas some distance from the processing facilities in most instances, will receive solid wastes containing hazardous substances.

FIGURE 20

CONCEPTUAL SCHEMATIC OF SUBMERGED COMBUSTION EVAPORATOR


EXHAUST
EXHAUST
GAS SUPPLY
VENTURI SCRUBBER
SCRUBBER SEPARATOR
SEPARATOR
VENTURI
FEED CHAMBER
COMBUSTION CHAMBER
BURNER
PRODUCT
FEED
SCRUBBER BLEED
SCRUBBER FEED
CIRCULATING PUMP
AIR BLOWER

The size and shape of the conventional landfill is optional, with major stipulations concerning the cover placed over the buried sludges. Since the sludges may contain some sulfides they should not be exposed to air under moist conditions. Exposure to air (oxygen) and water may result in conditions similar to those causing acid mine drainage--oxidation of iron sulfides or pyrites to form sulfuric acid. Therefore the sludges in a conventional landfill must be covered with at least four feet of soil and suitable vegetation cover. The vegetation produces organic matter in the soil which consumes oxygen in the decay process, thereby depleting the oxygen in the infiltrating air.[87]

In regions of high precipitation secured landfills will serve as burial sites for hazardous waste sludges that have been incorporated in asphalt or other suitable matrices to limit the leachability of these potentially toxic materials. Secured landfills may be located in areas of low population density, of low value for alternative land use, and where the potential for groundwater contamination is low. Desirable siting characteristics for landfills of this type are discussed in Chapter VI.

In addition to facilities and equipment normally required for trenching and backfilling operations, the secured landfill site will have an asphalt mixing plant for incorporating the hazardous sludges in a leach-resistant matrix.

It is anticipated that the number of secured landfill operations will be limited to take advantage of economies of scale in operating the asphalt mix plant and to avoid proliferation of these operations. The asphalting process involves mixing the wet sludge cake with molten-base asphalt in a wiped-film evaporator. The evaporator removes water from the sludge and intimately disperses the dry sludge particles in the asphalt. The product, which contains about 60 percent dry weight solids and 40 percent asphalt, flows from the evaporator at 120°C to 160°C. Incorporation of radioactive wastes in asphalt has proved effective in reducing the leach rates of the radioisotopes and should be equally effective for nonradioactive wastes.[88] It may be possible to use other materials such as waste polyethylene and proprietary agents for waste fixation; however, the leaching characteristics of these mixtures are not as well known as that of asphalt.

Disposal of the asphalt-waste mixtures will be accomplished by pumping or draining these mixtures directly into the burial trench. A solid impenetrable mass will thus be formed in the trench which is subsequently covered with a layer of clay and capped with at least 5 feet of soil. The clay layer will reduce water infiltration to the asphalt-waste mass. The trenches will be spaced to allow some water infiltration past the asphalt-waste mass to avoid saturating the soil. Rainfall infiltration will be further minimized by sloping the burial site to aid runoff.

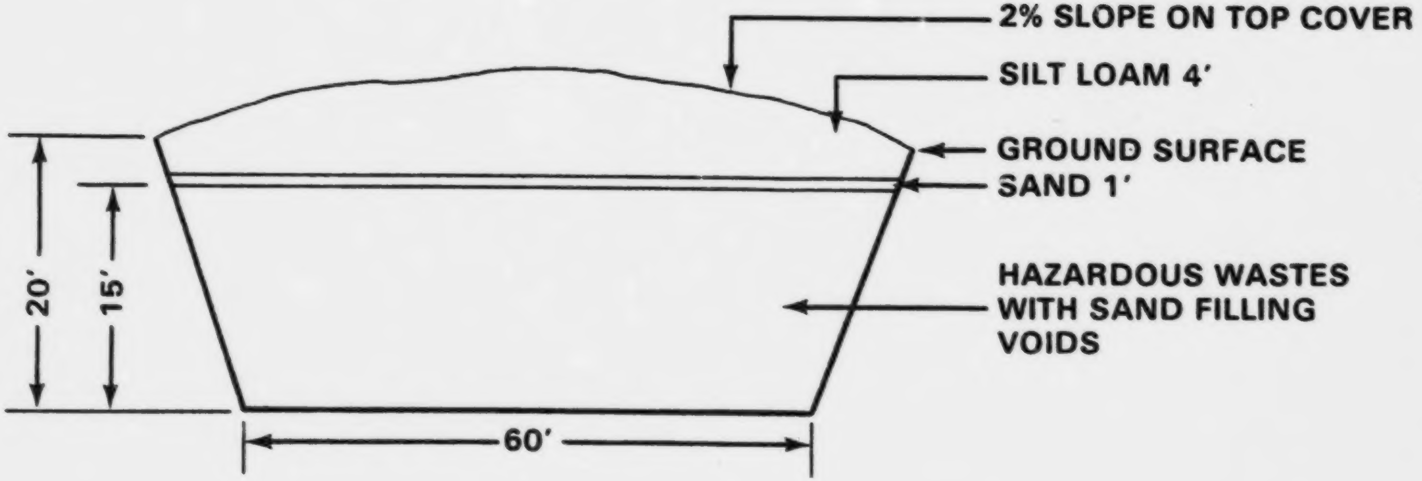
Secured landfills located in arid regions of the western United States may be used under suitable conditions for disposal of hazardous waste sludges without asphalt incorporation. Low rainfall and high evaporation rates (i.e., evaporation exceeds rainfall by a factor of 2) are needed to minimize water infiltration into burial trenches. Although the hazardous substances in the buried sludges are relatively insoluble, continued leaching would nevertheless be a potential problem. To further minimize water infiltration the buried waste is covered with a layer of sand topped by a layer of silty loam or clay. This procedure can effectively block water infiltration in areas of low rainfall and high evaporation rates. Water cannot penetrate the sand layer until the fine soil layer is nearly saturated.[89] Complete saturation of the fine soil would be unlikely to occur under the rainfall and evaporation conditions described above. A cross section of a secured landfill is illustrated in Figure 21. Plastic liners or barriers are not included in the secured landfill design because of the finite life of these materials. The silt and sand layers provide greater long-term assurance against water infiltration.

Secured landfills will be located away from flood plains, natural depressions, and slopes exceeding 5°. The burial site will be fenced and guarded to prevent public access. Burial trenches will be marked with permanent, concrete monuments warning of the nature of the hazardous contents of the trench in the event that surveillance is discontinued at some time in the future.

Although an effort will be made to minimize the amount of hazardous heavy metals in the sludges buried in local conventional landfills, studies are needed to verify the adequacy of this approach. It is reported that the solubility of arsenic decreases as the ratio of iron to arsenic increases in the neutralization-precipitation of these two substances.[52] Therefore a sludge low in arsenic and high in iron should have low arsenic leachability. The effect of organic degradation on the leachability of the sludges may also be an important consideration since significant pH changes or chemical reactions may occur as a result of biological activity.

FIGURE 21

CONCEPTUAL SCHEMATIC OF SECURED LANDFILL


2% SLOPE ON TOP COVER
SILT LOAM 4′
GROUND SURFACE
SAND 1′
HAZARDOUS WASTES WITH SAND FILLING VOIDS
20′
15′
60′

BRINE DISPOSAL

Brine disposal will be accomplished by either ocean disposal or deep well injection. The waste brines will be given sufficient treatment to reduce the concentrations of hazardous and polluting subtances to acceptable levels prior to discharge.

Ocean disposal of chemical wastes is regulated under Public Law 92-532 which requires a permit from the Environmental Protection Agency. Authorization to dispose of wastes by this method is dependent upon, but not limited to the following:

- the need for proposed disposal;
- the effect of such disposal on human health and welfare (including economic, esthetic, and recreational values);
- the effect on fish resources, plankton, shellfish, wildlife, shorelines and beaches;
- the effect on marine ecosystems, particularly with respect to
    1. the transfer, concentration, and dispersion of such materials and byproducts through biological, physical, and chemical processes,
    2. potential changes in marine ecosystem diversity, productivity, and stability, and
    3. species and community population dynamics;
- the persistence and permanence of the effects of the dumping;
- the effect of disposal of particular volumes and concentrations of such materials;
- appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of such alternate locations or methods upon considerations affecting the public interest; and
- the effect on alternate uses of the oceans, such as scientific study, fishing, and other living and nonliving resource exploitation.

In designating recommended sites for ocean disposal, the Administrator is constrained to utilize wherever possible locations beyond the edge of the continental shelf.

Deep well injection involves pumping the waste into deep wells where it is dispersed and contained in the pores of permeable subsurface rock. The injection zone is separated from other groundwater supplies by an impermeable layer of rock or clay. A conceptual schematic of an injection well is illustrated in Figure 22.

Regulations governing deep well injection of wastes are not uniform; the appropriate state agency must be consulted to obtain approval for disposal of wastes in this manner. EPA intends to regulate deep well injection under the National Pollutant Discharge Elimination System (Federal Register, December 5, 1972, pp. 25898-25906).

PROCESS PERFORMANCE LEVELS

The model processing facility includes the best available technology for treatment of hazardous wastes. A high level of performance will be maintained to minimize residual concentrations of contaminants in the facility effluents. With regard to the brine wastes, Table 13 lists the best performance levels (i.e., effluent concentrations) reported in the literature for the types of processes employed in the model processing facility. Evaporation of the brine wastes when required is expected to reduce nonvolatile consituents (e.g., heavy metals) in the condensate waste stream by several orders of magnitude.

Performance levels for incinerator systems for gaseous wastes have not been well defined. Except for particulate matter, sulfur oxides, nitrogen oxides, and total hydrocarbons, little quantitative data on the character of gaseous discharges from these systems has been reported. Performance data reported on particulate emission and combustion of organics in a rotary kiln incinerator are ≤0.1 grains per standard cubic foot of off-gas and >99.9 percent, respectively.[90] Measurements on individual organic groupings, such as pesticides, have indicated 99.99 percent destruction, measured by determining total organic carbon of effluents, fly ash, and gas.

RESOURCE RECOVERY

Resource recovery is viewed as a desirable goal in hazardous waste management since it accomplishes the removal of one or more potentially hazardous components of waste streams and the simultaneous conservation of material resources. The Resource

FIGURE 22

CONCEPTUAL SCHEMATIC OF INJECTION WELL

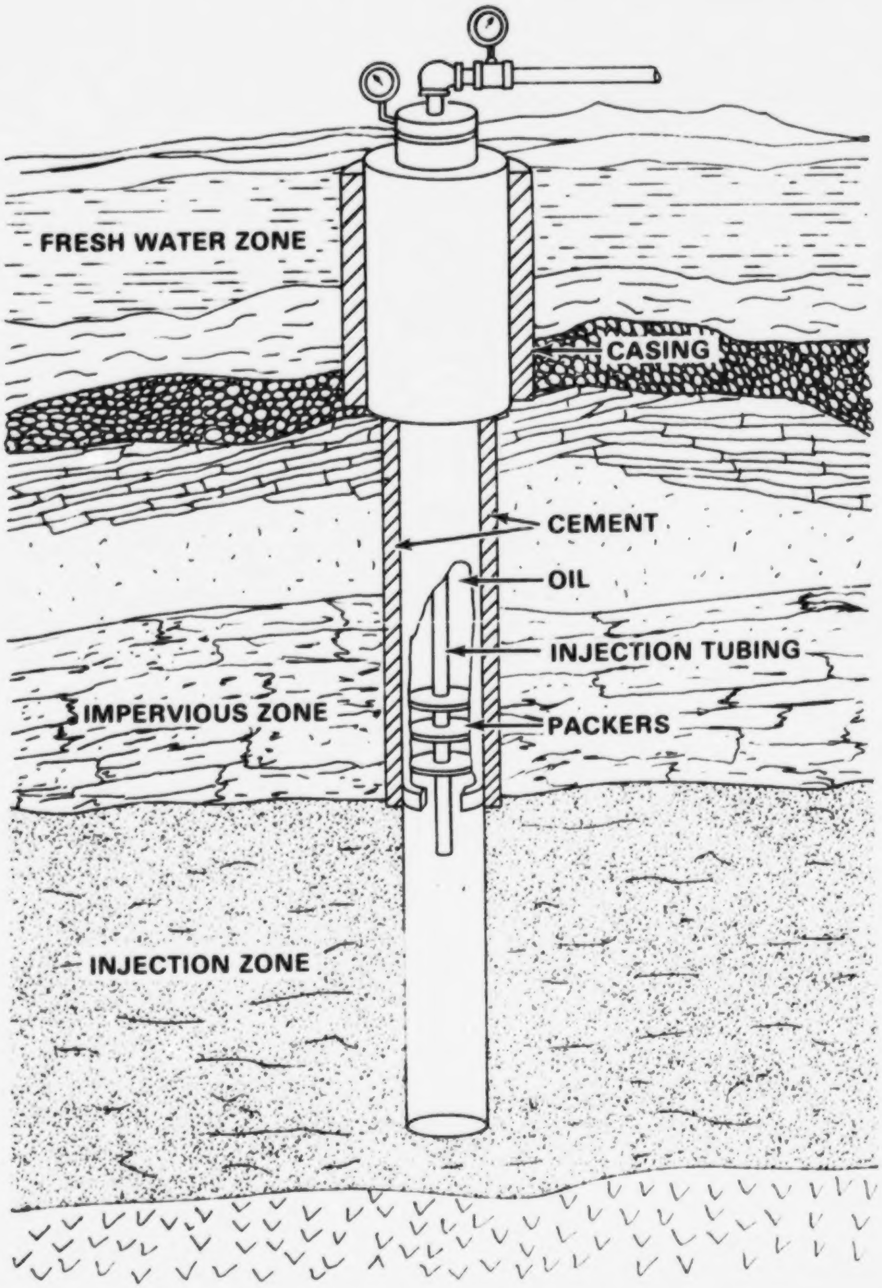

FRESH WATER ZONE
CASING
CEMENT
OIL
INJECTION TUBING
IMPERVIOUS ZONE
PACKERS
INJECTION ZONE

TABLE 13

BEST CURRENTLY EXISTING PERFORMANCE LEVELS FOR BRINE WASTES[50,73,91]

Constituent	Concentration (mg/1)
Cyanide	0.01
Chromium-6	0.01
Cadmium	0.01
Copper	0.2
Zinc	0.5
Iron	0.5
Lead	0.05
Arsenic	0.05
Fluoride	2.0
Aluminum	0.2
Manganese	1.0
Nickel	0.1
Silver	0.05
Zinc	0.5

Recovery Act of 1970 places great emphasis on the recovery and reuse of resources. In addition, the removal of recoverable materials would reduce the quantity of a waste stream and, consequently, the cost of handling and disposal. The recovery of energy from wastes would conserve energy resources. Finally revenue from the reutilization of recovered material and energy would reduce the net cost of waste handling and disposal.

Various organic solvents in waste streams are being recovered on a commercial scale by Chem-Trol Pollution Services, Inc., Buffalo, New York. This organization approaches resource recovery problems from the chemical processing viewpoint, including chemical analyses, laboratory feasibility studies, and pilot plant operations. Solvent extraction has been used by the Bureau of Mines to recover phosphates and metals from phosphate sludges.[92,93] Although the recovery process is not practiced on a commercial scale, the results of the Bureau of Mines' study indicate the feasibility of the process.

Although it may be important to recover energy resources by processes such as pyrolysis and anaerobic digestion, these were not considered in this study.

Candidate Recovery Materials

As a result of review of candidate wastes for disposal at a hazardous waste processing facility, the following two waste categories were selected for resource recovery analysis:

- metal finishing wastes containing valuable heavy metals such as cadmium, chromium, nickel, and copper, and
- waste oils and solvents.

Wastes from metal finishing operations are prime candidates for resource recovery. Such waste streams are in the form of sludges generated at either manufacturing plants or the waste processing facility. Among heavy metals, copper and nickel are prime candidates for recovery since their concentrations in the wastes are relatively high and they are more valuable than most other common heavy metals.

Although the bulk of the oils and solvents are not hazardous wastes, recovery of these materials may provide sufficient economic incentive for inclusion of the appropriate processes in a hazardous waste processing facility. Market surveys of the area in question can be conducted to determine the profitability of oil and/or solvent recovery.

Recovery of Heavy Metals

Well developed hydrometallurgical extraction processes may be employed on waste sludges to recover heavy metals. Since the processing scheme should be designed to facilitate the eventual recovery of heavy metals, various treatment steps such as filtration, neutralization, and electrolysis were included in the overall system.

Figure 23 shows the recommended metal recovery scheme for a site processing 50 tons per day of sludge from metal finishing wastes. The first step of the scheme is leaching of solubilized heavy metals from the sludge by sulfuric acid. The slurry is filtered to remove impurities such as calcium sulfate, after which the filtrate is neutralized with lime to pH 3 to precipitate and remove iron selectively as ferric hydroxide. Ferric hydroxide precipitate is then removed by filtration and the filtrate is electrolyzed under controlled potential for copper and nickel recovery. The remaining acidic solution is treated with lime to achieve pH 9. At this point the remaining heavy metals, such as chromium, cadmium, and zinc, are precipitated and removed as a sludge.

The basic reactions which take place in the recovery scheme are shown below.

Leaching:

$$Cr_2O_3 + 3H_2SO_4 = Cr_2(SO_4)_2 + 3H_2O$$

$$Cu\ (OH)_2 + H_2SO_4 = CuSO_4 + 2H_2O$$

$$Zn(OH)_2 + H_2SO_4 = ZnSO_4 + 2H_2O$$

$$Cd(OH)_2 + H_2SO_4 = CdSO_4 + 2H_2O$$

$$Fe_2O_3 + 3H_2SO_4 = Fe_2(SO_4)_3 + 3H_2O$$

$$Ni(OH)_2 + H_2SO_4 = NiSO_4 + 2H_2O$$

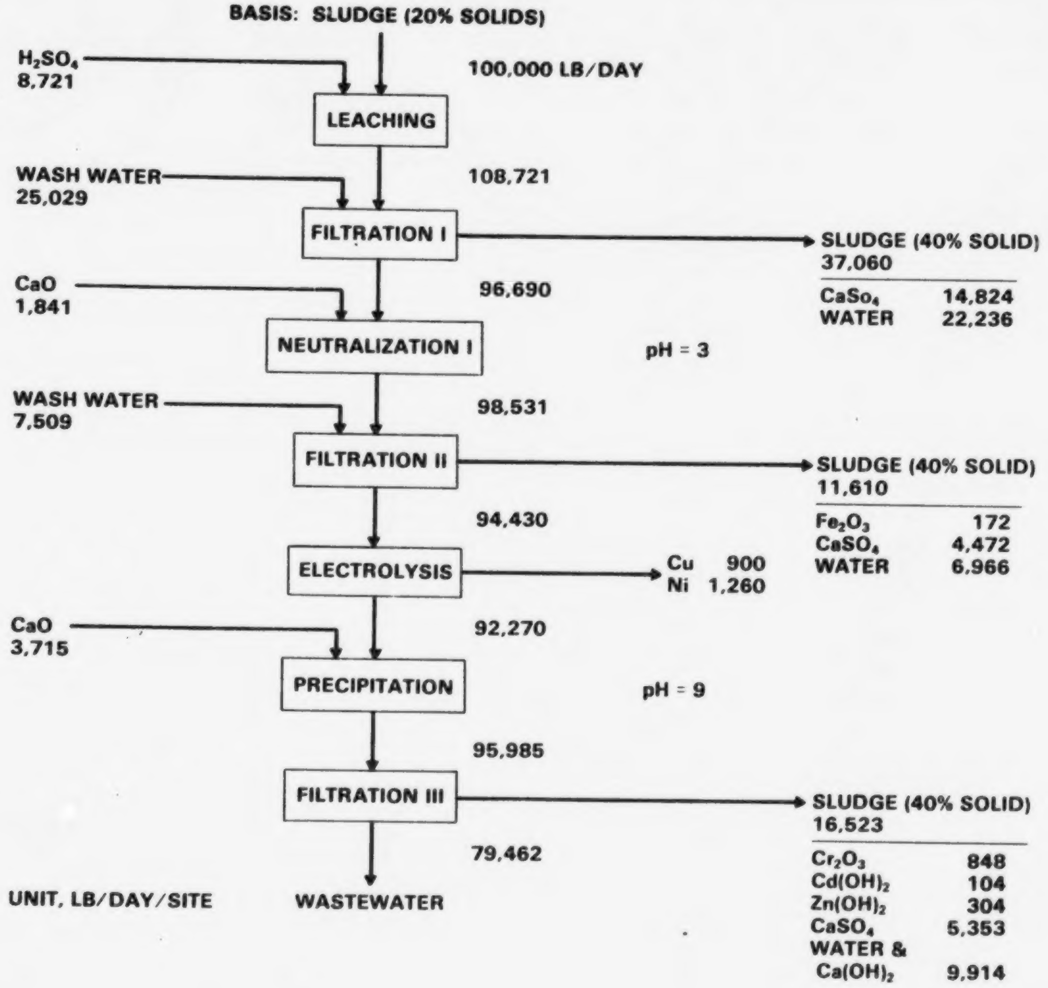
Neutralization I:

$$H_2SO_4 + CaO = CaSO_4 + H_2O$$

$$Fe_2(SO_4)_3 + 6H_2O + 3CaO = 2Fe(OH)_3 + 3CaSO_4 + 3H_2O$$

FIGURE 23

FLOW DIAGRAM OF THE RECOMMENDED METAL RECOVERY SCHEME FROM METAL-FINISHING WASTES


BASIS: SLUDGE (20% SOLIDS)
H_2SO_4 8,721
100,000 LB/DAY
LEACHING
WASH WATER 25,029
108,721
FILTRATION I
SLUDGE (40% SOLID) 37,060
$CaSo_4$ 14,824
WATER 22,236
CaO 1,841
96,690
NEUTRALIZATION I
pH = 3
WASH WATER 7,509
98,531
FILTRATION II
SLUDGE (40% SOLID) 11,610
Fe_2O_3 172
$CaSO_4$ 4,472
WATER 6,966
94,430
ELECTROLYSIS
Cu 900
Ni 1,260
CaO 3,715
92,270
PRECIPITATION
pH = 9
95,985
FILTRATION III
SLUDGE (40% SOLID) 16,523
Cr_2O_3 848
$Cd(OH)_2$ 104
$Zn(OH)_2$ 304
$CaSO_4$ 5,353
WATER & $Ca(OH)_2$ 9,914
79,462
UNIT, LB/DAY/SITE
WASTEWATER

Electrolysis:

$$2CuSO_4 + 2H_2O = 2Cu + O_2 + 2H_2SO_4$$

$$2NiSO_4 + 2H_2O = 2Ni + O_2 + 2H_2SO_4$$

Precipitation:

$$CdSO_4 + H_2O + CaO = Cd(OH)_2 + CaSO_4$$

$$ZnSO_4 + H_2O + CaO = Zn(OH)_2 + CaSO_4$$

$$Cr_2(SO_4)_3 + CaO + 6H_2O = 2Cr(OH)_3 + 3CaSO_4 + 3H_2O$$

The recovery scheme described has two merits; the scheme is simple and the metallic copper and nickel can be sold for a substantial credit. Based on the results of the plant design study (Appendix H), the total processing cost was estimated to be \$1642 per day and the credit for the copper and nickel recovered from the process was \$2,214 per day. The net income derived from the process would be estimated as \$572 per day. The processing cost could be reduced if sulfuric acid produced in the electrolysis step can be recycled to the leaching step. Additionally, income might be derived if chromium can be recovered in a salable form.

Recovery of Waste Solvents

A two-step process patterned after the solvent recovery method used by Chem-Trol Pollution Services, Inc. is recommended to recover useful solvents from waste solvents received by a hazardous waste processing facility. This process consists of (1) a preliminary recovery step using a agitated wiped film evaporator and (2) further fractionation by distillation.

The types and quantities of waste solvents anticipated for processing are summarized in Table 14. Physical properties of the solvents are also listed.

The solvent recovery system is shown schematically in Figure 24. Waste solvents will be received and stored in a holding tank or tanks. The size and number of these tanks will be dependent upon the characteristics and quantities of the wastes. For estimating first costs one tank was used. The waste solvents are pumped to an agitated wiped film evaporator, where solvents are recovered from residues contained in the waste

TABLE 14

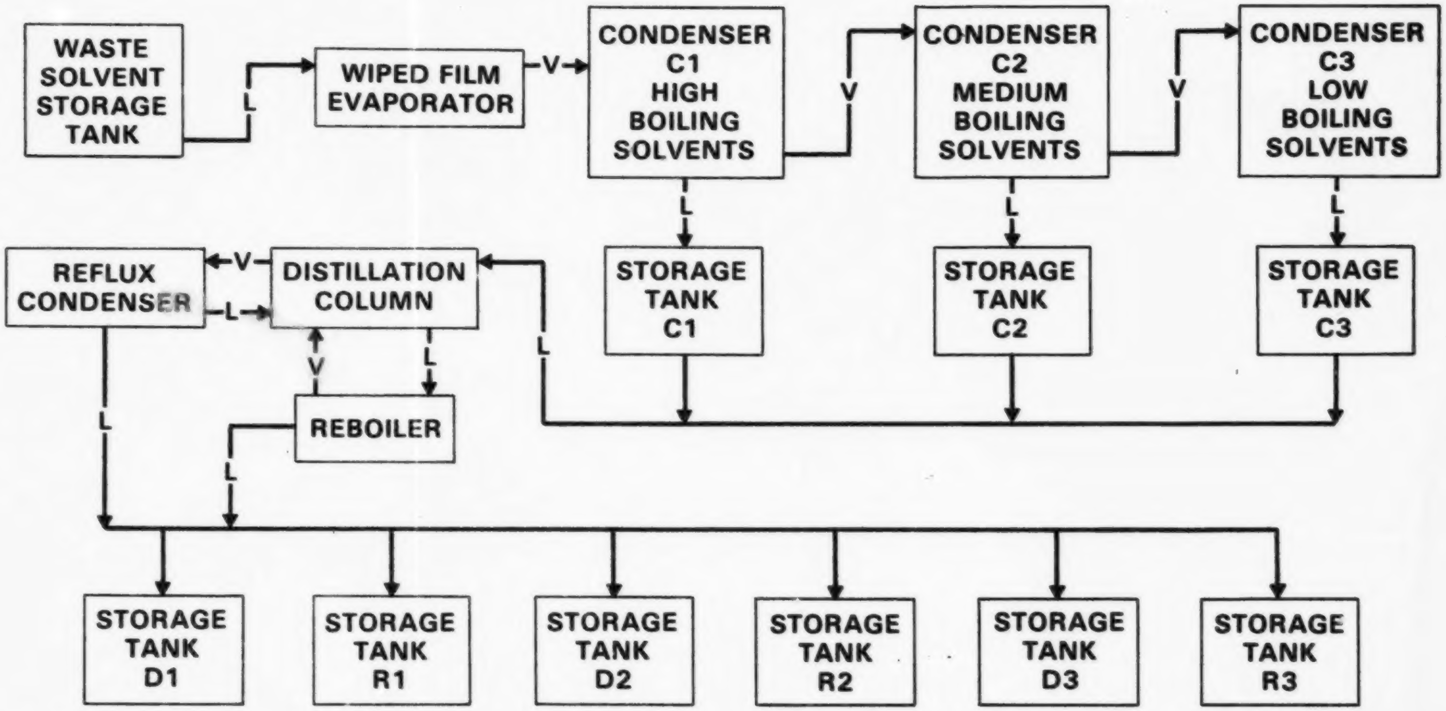
TYPES, PROPERTIES, AND QUANTITIES OF SOLVENTS ESTIMATED TO BE AVAILABLE FOR RECOVERY[94]*

Solvent	Chemical Formula	Quantity, lbs/yr	Molecular Weight	Boiling Point		Specific Gravity	Density lb/gal	Specific Heat BTU/lb/°F	Heat of Vaporization BTU/lb
				°C	°F				
Carbon Tetrachloride	CCl_4	4.5×10^8	153.8	76.8	170	1.59	13.22	.201	81.6
Chloroform	$CHCl_3$	0.5×10^8	119.4	61.2	142	1.48	12.35	.234	106.0
O-dichlorobenzene	$C_6H_4Cl_2$	0.5×10^8	147.0	179	353	1.298	10.80	.270	91.8
Ethylene dichloride	$CH_2Cl\text{-}CH_2Cl$	3.0×10^8	98.9	83	182	1.255	10.43	.319	153.2
Methyl chloroform	CH_3CCl_3	0.5×10^8	133.4	75	167	1.325	11.1	.238	129.5
Methylene chloride	CH_2Cl_2	1.5×10^8	84.9	41	104	1.322	11.1	.288	141.2
Perchlorethylene	$CCl_2 = CCl_2$	2.0×10^8	165.8	121	250	1.625	13.5	.211	90.2
Trichloroethylene	$ClHC = CCl_2$	2.0×10^8	131.4	88	190	1.477	12.3	.223	103.0

*50 percent of production values given in reference 94 except for ethylene dichloride, which is 15 percent.

FIGURE 24

SCHEMATIC OF SOLVENT RECOVERY PROCESS


WASTE SOLVENT STORAGE TANK
L
WIPED FILM EVAPORATOR
V
CONDENSER C1 HIGH BOILING SOLVENTS
V
CONDENSER C2 MEDIUM BOILING SOLVENTS
V
CONDENSER C3 LOW BOILING SOLVENTS
L
STORAGE TANK C1
L
STORAGE TANK C2
L
STORAGE TANK C3
REFLUX CONDENSER
V
L
DISTILLATION COLUMN
L
V
L
REBOILER
L
L
STORAGE TANK D1
STORAGE TANK R1
STORAGE TANK D2
STORAGE TANK R2
STORAGE TANK D3
STORAGE TANK R3

Legend: V = Vapor Stream, L = Liquid Stream, W1 = Waste Solvent Storage Feed, C1 = Condenser/Storage Tank for High-Boiling Solvents, C2 = Condenser/Storage Tank for Medium-Boiling Solvents, C3 = Condenser/Storage Tank for Low-Boiling Solvents, D1 = Storage Tank for Distillate from the First Cut, R1 = Storage Tank for Bottoms from the First Cut, D2 = Storage Tank for Distillate from the Second Cut, R2 = Storage Tank for Bottoms from the Second Cut, D3 = Storage Tank for Distillate from the Third Cut, R3 = Storage Tank for Bottoms from the Third Cut.

solvent by evaporation at atmospheric pressure. The solvent vapors are condensed in three successive condensers and separated into three cuts as follows:

- first cut: methylene chloride and chloroform;
- second cut: methyl chloroform, carbon tetrachloride, ethylene dichloride, and trichloroethylene;
- third cut: perchloroethylene and o-dichlorobenzene.

The three cuts are allowed to cool, then are stored in holding tanks awaiting further separation in a distillation column. Each cut is further fractionated individually.

The final makeup of the recovered solvents would be as follows, listed in the order of increasing boiling points.

1.	Methylene chloride	Distillate from the first cut
2.	Chloroform	Bottoms from the first cut
3.	Mixture of methyl chloroform and carbon tetrachloride	Distillate from the second cut
4.	Mixture of ethylene-dichloride and trichloroethylene	Bottoms from the second cut
5.	Perchlorethylene (tetrachloroethylene)	Distillate from the third cut
6.	O-dichlorobenzene	Bottoms from the third cut

A preliminary cost estimate (see Appendix I) based on processing of 14,000 gallons of typical solvent waste at a processing site indicates that about $7,000 per day of net income can be derived from the sale of recovered solvents. The solvent recovery process looks promising as a means of deriving a substantial income and it is therefore anticipated that private industry would include solvent recovery in many hazardous waste processing facilities.

Recovery and Utilization of Waste Oils

The total annual production of lubricants in the U. S. is estimated as follows:[95]

• Automobile crankcase oil	2×10^{10}	lb/year
• Industrial lubricating greases	1×10^{9}	lb/year
• Industrial lubricating oils	2×10^{10}	lb/year

Among the three listed above, disposal of waste automobile crankcase oil is the major item of concern at present. Industrial oils are in many instances effectively and economically recovered and reused. Greases constitute a minor volume item and consequently pose a relatively insignificant disposal problem. Waste crankcase oil, therefore, will be a prime candidate for routing to waste processing facilities.

Assuming that 50 percent of the virgin crankcase oil produced in the U. S. is shipped as waste to processing facilities for reprocessing or disposal, the quantity of the waste oil received by each site (based on 30 sites in the United States) is estimated as 2.2×10^6 pounds per day. The alternatives available for reprocessing or disposal of the waste crankcase oil include:

1. reprocessing into useful products;
2. burning as a fuel for evaporative concentration of aqueous wastes; and
3. burning as a fuel in a boiler plant.

Reprocessing

A recent process development study[96] conducted by National Oil Recovery Corporation indicates the feasibility of reprocessing spent crankcase oil into useful petroleum products other than lubricating oil. The average selling price of the products is estimated as 7 cents per gallon. The total processing cost, based on 42,000 gallons per day (about 0.3×10^6 pounds per day), is estimated as 7 cents per gallon. The latter cost includes 3 cents per gallon allowed for the collection of waste oil. For larger plants, the processing cost might be reduced to 5 or 6 cents per gallon, making this process economically viable.

Fuel for Evaporation/Concentration of Aqueous Wastes

Waste oil could also be utilized in the evaporative concentration of aqueous wastes. The current approach is based on the use of a natural gas fueled submerged combustion evaporator. The waste oil could be substituted for natural gas to achieve a significant saving in the fuel cost. Based on a heating value of 15,000 BTU per pound for the waste oil and an evaporator designed to handle 200,000 gallons per day of aqueous wastes, the daily consumption and utilization of waste oil in this manner is estimated as 0.13×10^6 pounds per day.

Fuel for Boiler Plant

The waste oil could be burned as a supplemental fuel in a boiler to make steam for use at the waste processing facility. A recent API task force study[97] indicates that waste crankcase oil can be safely added to residual fuel oil in proportions up to 25 percent and burned to produce useful heat.

EFFLUENT MONITORING

Essentially two aqueous waste streams are discharged by the model processing facility. The principal one is either a brine (which receives ocean disposal or deep well injection) or a condensate (which is discharged to local fresh or ocean receiving waters). The second aqueous waste stream consists of plant cooling and service water which is normally free of hazardous and/or polluting materials. Plant cooling and service effluent water will be monitored regularly to detect leakage in the systems involved. Proportional samplers will be used to collect daily composite samples for analysis. Physical and chemical parameters of these waste streams to be determined on a routine basis include the following.

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Organic Carbon (TOC)
- Temperature
- pH
- Dissolved Solids
- Suspended Solids
- Specific Organics of Interest
- Chromium-6
- Cyanide
- Cyanate

- Heavy Metals
- Ammonia
- Nitrate
- Phosphate
- Fluoride
- Sulfide

Certain process streams will be monitored continuously to detect unexpected or off-standard performance upon occurrence. Effluent from the tri-media filters will be continuously monitored for sulfide ion and turbidity. The lack of sulfide ion or the presence of turbidity are indications of possible heavy metal leakage through the liquid-solids separation module. Feed to the carbon sorption module will be monitored for residual chlorine. The presence of trace residual chlorine indicates that oxidation of excess sulfide ion has occurred. This residual chlorine is removed in the carbon columns. Effluent from the carbon sorption module is monitored continuously for total organic carbon, which is used as a rough guide to evaluate performance of the carbon beds.

Gaseous effluents from the incinerator system will be monitored for the following components.

- Smoke
- Particulates
- Moisture
- Carbon Dioxide
- Carbon Monoxide
- Excess Air (O_2)
- Sulfur Oxide
- Nitrogen Oxides
- Hydrogen Chloride
- Total Organic Carbon
- Specific Organics of Interest
- Heavy Metals

A photoelectric smoke detector will be used to continuously monitor gaseous emissions from the incinerator system.

The analytical laboratory will be provided with the necessary facilities to analyze samples for feed composition verification, process control, pilot plant operations, effluent monitoring, and environmental monitoring. In addition to the normal equipment and reagents needed for wet chemical analysis, the analytical laboratory also should be equipped with the following specialized equipment.

- Vapor Phase Chromatograph (2)
- Atomic Adsorption Apparatus (2)
- Colorimeters (2)
- Infrared Spectrophotometer
- Ultraviolet--Visible Spectrophotometer
- Total Organic Carbon Apparatus
- Turbidometer
- Viscometer
- Kjeldahl Apparatus
- Jar Test Machine

TRANSPORTATION OF WASTES FOR PROCESSING

Technical and cost information has been developed for existing transportation practices and systems, including containers, transporters, and loading and unloading requirements, to transport wastes to the processing facilities. Waste categories excluded from consideration in this effort were radioactive wastes and DOD related materials (CBW agents, ordnance, and explosives). Cost details related to waste transportation and storage are given in Appendix L.

It is anticipated that the bulk of the wastes will be transported to the treatment facilities by truck. Estimated cost of this transportation mode is $12 per ton based on an average hauling distance of 150 miles and the truck rate given for more than 40,000 pounds in Table A-86 of Appendix L. A specific gravity of 1.08 was assumed for liquid wastes.

Cost Estimates

Processing Facilities

Preliminary cost estimates were prepared for three different sizes of model processing facilities. Capital and operating costs were initially estimated for a medium sized model facility which would have processing capability for 122,000 gallons per day of aqueous-inorganic wastes and 74 tons per day of combustible wastes. Capital and operating costs were then estimated for a small facility and a large facility using the 0.6 scale-up factor for all equipment but the multiple submerged combustion units, for which a scale-up factor of 0.9 was used. The small processing facility is sized to process 25,000 gallons per day of aqueous-inorganic wastes and 15 tons per day of combustible wastes, while the large plant is sized to process one million gallons per day of aqueous-inorganic wastes and 607 tons per day of combustible wastes.

Capital and operating cost summaries of medium, small, and large facilities are presented in Tables 15, 16, and 17, respectively. The summaries include a breakdown of capital and operating costs for each module. Included in the data for each module are the costs for land, buildings, laboratory, offices, and auxiliary equipment. These cost data are based on preliminary estimates which include many approximations and simplifying assumptions. More accurate estimates would involve detailed material and energy balances around the system and its various internal components so that the individual items of equipment, reaction vessels, and tanks could be sized and estimated with greater accuracy. Further cost details of the three facilities are given in Appendix J.

The most significant costs are incurred in the receiving storage modules, the chemical treatment module, and the liquid-solids separation module. In the medium size receiving-storage module (Table 15), labor (including supervision and laboratory personnel) accounts for about 50 percent of the operating cost and facilities (capital amortization) for 28 percent of the cost of this module. The major cost items in the chemical treatment module are treating chemicals and processing facilities. The lime handling system alone accounts for almost 70 percent of the total capital cost of this module. Chemical consumption represents about 45 percent and facilities about 23 percent of the operating cost. The major cost factor in the liquid-solids separation module is the facility cost, wherein capital amortization accounts for about half the total operating cost.

TABLE 15

PRELIMINARY COST ESTIMATE SUMMARY FOR MEDIUM SIZE PROCESSING FACILITY

CAPACITY: 122,000 gpd Aqueous Waste Treatment
74 tons/day Incineration
260 day/year Operation

TOTAL FIXED CAPITAL COST: $24,070,000

MODULAR CAPITAL AND OPERATING COSTS: AQUEOUS WASTE TREATMENT

Module	Fixed Capital Cost,$	Daily Operating Cost,$	Ave. Cost Per 1000 Gal,$
Receiving & Storage	3,270,000	6,424	46.40
Ammonia Stripping	773,800	952	7.80
Chemical Treatment	4,734,000	11,307*	84.70
Liquid-Solids Separation	8,963,700	9,516*	39.60**
Carbon Sorption	941,000	1,578*	7.40
Evaporation	514,000	2,173*	10.20
Rounded Totals	19,200,000	32,000	196.00

MODULAR CAPITAL AND OPERATING COSTS: INCINERATION

Module	Fixed Capital Cost,$	Daily Operating Cost,$	Ave. Cost Per ton,$
Incinerator	4,873,000	7,000	94.60
	Scrubber Wastewater Treatment	(90,000 gpd)	80.60
		Total	175.00

---

* Includes processing cost for incinerator scrubber wastewater

** Excludes processing cost for clarifying incinerator scrubber wastewater

TABLE 16

PRELIMINARY COST ESTIMATE SUMMARY FOR SMALL SIZE PROCESSING FACILITY

CAPACITY:	25,000 gpd	Aqueous Waste Treatment
	15 tons/day	Incineration
	260 day/year	Operation

TOTAL FIXED CAPITAL COST: $9,300,000

MODULAR CAPITAL AND OPERATING COST: AQUEOUS WASTE TREATMENT

Module	Fixed Capital Cost,$	Daily Operating Cost,$	Ave. Cost Per 1000 Gal,$
Receiving & Storage	1,262,000	1,881	66.20
Ammonia Stripping	298,700	461	18.40
Chemical Treatment	1,827,300	3,298*	150.50
Liquid-Solids Separation	3,460,000	3,888*	80.10**
Carbon Sorption	363,000	758*	17.50
Evaporation	198,000	635*	14.60
Rounded Totals	7,410,000	10,900	347.00

MODULAR CAPITAL AND OPERATING COST: INCINERATION

Module	Fixed Capital Cost,$	Daily Operating Cost,$	Ave. Cost Per ton,$
Incinerator	1,880,000	3,200	213.00
Scrubber Wastewater Treatment		(18,450 gpd)	185.00
		Total	398.00

---

* Includes processing cost for incinerator scrubber wastewater.

** Excludes processing cost for clarifying incinerator scrubber wastewater.

TABLE 17

PRELIMINARY COST ESTIMATE SUMMARY FOR LARGE SIZE PROCESSING FACILITY

CAPACITY: 1,00,000 gpd Aqueous Waste Treatment
607 tons/day Incineration
260 day/year Operation

TOTAL FIXED CAPITAL COST: $86,000,000

MODULAR CAPITAL AND OPERATING COSTS: AQUEOUS WASTE TREATMENT

Module	Fixed Capital Cost,$	Daily Operating Cost,$	Ave. Cost Per 1000 Gal,$
Receiving & Storage	11,543,000	38,150	33.60
Ammonia Stripping	2,731,500	3,180	3.18
Chemical Treatment	16,710,600	60,630*	53.83
Liquid-Solids Separation	30,915,700	34,687*	17.18
Carbon Sorption	3,322,000	6,290*	3.62
Evaporation	3,413,000	15,947*	9.16
Rounded Totals	68,600,000	159,000	121.00

MODULAR CAPITAL AND OPERATING COSTS: INCINERATION

Module	Fixed Capital Cost,$	Daily Operating Cost,$	Ave. Cost Per ton,$
Incinerator	17,201,700	27,374	45.10
	Scrubber Wastewater Treatment	(738,000 gpd)	55.70
		Total	101.00

---

* Includes processing cost for incinerator scrubber wastewater.

** Excludes processing cost for clarifying incinerator scrubber wastewater.

The high cost of the small module facility makes its value questionable. In particular, the high cost of incineration at the small facility would almost certainly cause potential customers to ship their combustible wastes to larger facilities. The cost differential between the large and small facilities for incineration of combustible hazardous wastes is about $200 per ton, which is considerably more than shipping costs for even large distances. The greater than $200 per 1000 gallon differential on aqueous-waste treatment between the small and large module facility would also tend to encourage shipment of the wastes to larger facilities.

The overall cost for a national system of processing facilities cannot be accurately estimated at this time due to uncertainties in the locations of the sources of hazardous wastes and the volumes generated at each source. The number and sizes of the treatment facilities will be governed by distribution of the sources and the total volume of wastes in a given area. The total volume generated nationally is estimated to be 10 million tons per year. Of this amount 15 percent, or 1.5 million tons, consists of dilute wastes which can be reduced on-site to one-third the original volume by simple treatment methods (e.g., lime treatment to precipitate dilute heavy metals). The concentrate, slurry, or sludge, estimated to be 0.5 million tons annually, is then shipped to a treatment facility for further processing. The estimated total volume of hazardous wastes to be received at a national system of treatment facilities then becomes 9 million tons per year.

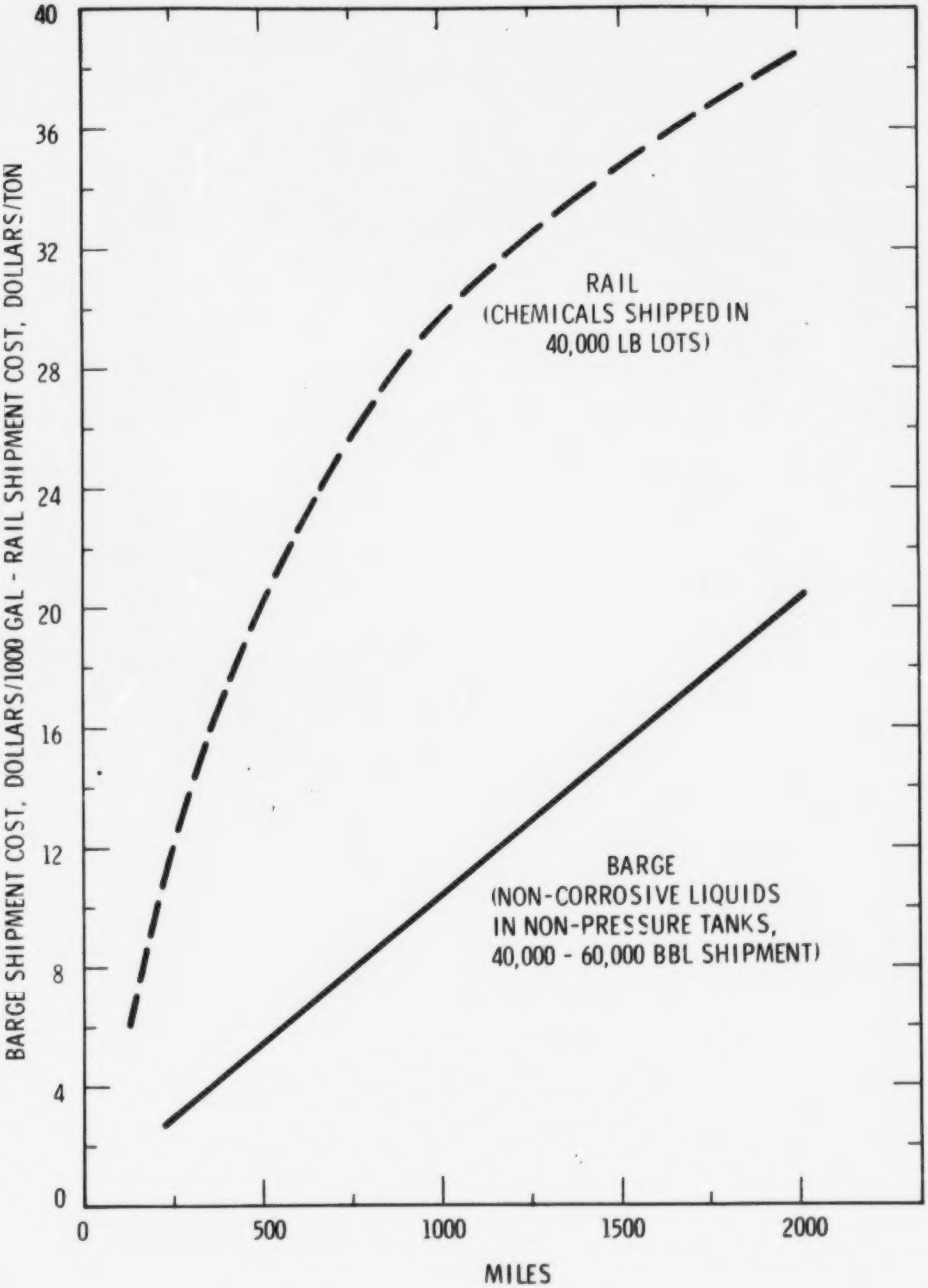
If it is assumed that only large or medium size treatment facilities will be constructed the total capital cost would range from $602 million (for 7 large facilities) to $1.35 billion (for 56 medium facilities). A reasonable combination of facilities can be postulated on the basis of 5 large treatment facilities for heavily industrialized areas and 15 medium facilities serving lightly industrialized areas. The total capital cost for a system of 5 large and 15 medium facilities would be $791 million. The estimated annual operating cost of this system for treatment only would be $381 million.

Disposal Costs

Disposal methods for brine wastes include ocean disposal and deep well injection into salaquifers. The cost incurred for ocean disposal is essentially that for transporting the brine to a suitable site at sea. Barge shipment costs as a function of distance are illustrated in Figure 25 together with rail shipment cost. These cost data are based on averages and are subject to fluctuation depending on the area involved.[64] Lower cost rail rates than those given in Figure 25 may be negotiated for bulk shipments.

FIGURE 25

RAIL AND BARGE SHIPMENT COSTS AS A FUNCTION OF DISTANCE



In general, deep well injection costs range from $0.50 to $5.00 per thousand gallons injected.[64] The cost depends on many variables including the depth of the well, type of well, injection pressure and treatment required. Anticipated costs for injecting clarified brine waste into a 6000 foot well at a rate of 225,000 gpd is about $1.00 per thousand gallons.[98] This injection system does not include elaborate clarification facilities since the brine effluent from the model processing facility has been previously clarified and filtered. On-site deep well injection of waste brine, if feasible, would cost $212 per day for the medium sized processing facility.

Costs incurred for conventional landfill of salt cake and sludge cake without significant concentrations of hazardous substances are expected to be near $2.00 per ton.[64] Significant costs may be incurred for salt cake disposal due to charges for shipping this material to an arid region landfill (not a secured landfill).

The quantity of sludge generated daily by a medium sized treatment facility is estimated to be 275 tons/day or 44 percent of the total waste received. On this same basis, a large facility would generate 2250 tons of sludge per day. Five percent of this sludge will be generated on a campaign basis to concentrate the hazardous heavy metals in a relatively small volume for disposal to a secured landfill. The remaining sludge can be disposed to a conventional sanitary landfill. The average cost for disposal to a sanitary landfill is estimated to be $2.00 per ton.[64] Transportation costs would add an estimated $1.00 per ton, based on an average hauling distance of ten miles.

The cost for burial of sludge containing significant quantities of hazardous heavy metals is estimated to be $32 per ton. This cost is based on a secured landfill operation handling 157 tons per day of sludge and includes the cost of incorporating the sludge in asphalt. The asphalting cost represents about two-thirds of the total cost of the secured landfill operation. Five secured landfill operations of this size, costing about $2 million each, would be sufficient to dispose of all of the sludge with hazardous metals generated by a national system of treatment facilities. Secured landfills would be located as near as possible to the large treatment facilities to minimize transportation costs. For example, the estimated cost of transporting hazardous waste sludge 30 miles from a large treatment facility to a secured landfill is about $3 per ton. Therefore, the total cost in this case for transport and disposal would be $35 per ton. Transportation costs for hauling sludge an average of 500 miles by rail from a medium sized treatment facility to a secured landfill would add an estimated $20 per ton to the disposal cost, for a total of $52. The costs of operating a medium and large facility, including transportation and disposal costs, are given in Table 18. These costs do not include on-site treatment at the waste source. The total annual operating costs for a national system of 5 large and 15 medium treatment facilities would be $577 million.

TABLE 18

ANNUAL OPERATING COSTS FOR A MEDIUM AND A LARGE TREATMENT FACILITY

Cost Item	Annual Operating Costs, Millions of Dollars	
	Medium Facility	Large Facility
Waste Transport*	1.9	15.9
Treatment (Excludes Evaporation)	11.2	53.1
Sludge Disposal to Secured Landfill	0.2	1.0
Sludge Disposal to Conventional Landfill	0.2	1.7
Waste Brine Disposal**	0.3	2.3
Totals	13.8	74.0

---

*Waste transportation costs are based on an average distance of 150 miles at a cost of $12 per ton.

**Brine waste disposal costs are $5 per 1000 gallons which is the equivalent of barge transport 500 miles to an ocean disposal site.

CHAPTER CONTENTS

CHAPTER V

RADIOACTIVE WASTES

	Page No.
BRIEF	151
FINDINGS AND CONCLUSIONS FOR RADIOACTIVE WASTES	151
BACKGROUND OF RADIOACTIVE WASTE MANAGEMENT POLICIES AND RADIATION PROTECTION REGULATIONS IN THE U.S.	157
Overall Legislative History	157
General Dose and Effluent Considerations	159
Disposal or Long-Term Storage of Wastes	161
Administrative Arrangements	161
Federal Regulation and Control	162
State Regulation and Control	164
RADIOACTIVE WASTES AND A NATIONAL SYSTEM FOR HAZARDOUS WASTE MANAGEMENT	165
CATEGORIES OF RADIOACTIVE WASTES IN A NATIONAL DISPOSAL SYSTEM	167
Potential Radiological Toxicities Associated With Radioactive Wastes	168
SOURCES OF RADIOACTIVE WASTES	168
RADIOACTIVE WASTES FROM THE COMMERCIAL NUCLEAR POWER INDUSTRY	170
QUANTITIES, CONSTITUENTS, DISTRIBUTION	171
PROSPECTIVE WASTES FROM THE NUCLEAR FUEL CYCLE	171
RADIOACTIVE WASTES FROM MISCELLANEOUS PRIVATE SOURCES	181

CHAPTER CONTENTS (Continued)

Page No.

RADIOACTIVE WASTES FROM GOVERNMENT SOURCES 183

Atomic Energy Commission Sources 183

Distribution and Types of Wastes 184

- Production Rate of Solid and Liquid Wastes 184
- Cumulative Generation of Solid Wastes 184
- Radionuclide Content of the AEC Wastes 184
- Waste Compositions 196
- Detailed Inventory of a Selected AEC Site--Hanford 196

Department of Defense Sources 196

TRANSPORTATION OF RADIOACTIVE WASTES 199

Regulations for Transportation of Radioactive Wastes 199

Transportation Safety Requirements 200

Bases for Transportation System Requirements 200

Design of Transportation Systems for Radioactive Wastes--Containers and Protection 201

- Methods of Transportation 203
- Distances from Sources to Disposal Sites 203
- Methods and Equipment for Handling Small Radioactive Waste Accidents and for Decontamination Transport Systems 205
- Accountability of Radioactive Waste Materials Associated with Transportation 205

RADIOACTIVE WASTE MANAGEMENT SYSTEM DESIGN 205

Bases for Radioactive Waste Disposal 205

Types and Quantities of Radioactive Wastes 207

- Government Wastes 207
- Solid Wastes 207
- Liquid Wastes 208
- Gaseous Waste 210

CHAPTER CONTENTS (Continued)

Page No.

High-Level Radioative Waste--Strategy of Disposal 210

Potential of Partitioning High-Level Radioactive Wastes 214

Criteria and General Description for Retrievable High-Level Radioactive Waste Repository 214

Description of Retrievable Surface Storage Facility for High-Level Radioactive Waste 219
Unit Operations for Storage of High-Level Radioactive Wastes 222
Potential Retrievable Surface Storage of High-Level Radioactive Waste by the Sealed Storage Cask Concept 222
Costs for High-Level Radioactive Waste Repository 223

Transportation Costs for High-Level Radioactive Wastes 225

LOW-LEVEL RADIOACTIVE WASTES 228

Strategy for Disposal of Low-Level Radioactive Wastes 229

Criteria and General Description for Retrievable Low-Level Radioactive Waste Storage System 232

Description of Retrievable Surface Storage Facility for Low-Level Radioactive Wastes 234
Unit Operations for Storage of Low-Level Radioactive Wastes 239
Environmental Safeguards at the Repository Site for Low-Level Radioactive Waste 239
Safety Provisions 239
Accountability and Monitoring 240
Costs for Low-Level Radioactive Waste Disposal Site 242
Capital Costs 242
Operating Costs 244
Design and Construction Schedule 244

CHAPTER CONTENTS (Continued)

Page No.

Transportation Costs for Low-Level Radioactive Wastes 244

Costs of Retrieval of Buried Low-Level Radioactive Wastes 247

CHAPTER V

RADIOACTIVE WASTES

BRIEF

Most radioactive wastes consist of more or less conventional nonradioactive materials contaminated with radionuclides. The concentration of the latter can range from less than one part per billion to as much as 50 percent of the bulk constituents. More than one and frequently many radionuclides are involved in most wastes, which are customarily categorized as low to high-level wastes, depending upon the concentrations of radionuclides. The long-term hazard associated with each waste is not necessarily proportional to the nominal "level" of radioactivity, however; it is related more to the specific toxicity, mode of action and decay rate of each radionuclide and its chain of daughters. The most significant radionuclides, from the standpoint of waste management, decay with half lives ranging from a few months to hundreds of thousands of years. For the purposes of this study, the term "high-level wastes" refers to those requiring special provisions for dissipation of radioactive decay heat. "Low-level wastes" refers essentially to all other radioactive wastes.

The biological hazard from radioactive wastes is primarily due to the effects of penetrating and ionizing radiation rather than to chemical toxicity. On a weight basis, the toxicities of some radionuclides are greater than those of the most poisonous chemicals by about six orders of magnitude and cannot be "neutralized" by chemical reaction or by any currently practicable scheme. Thus, the only currently practical way to "eliminate" a radionuclide is to allow it to decay during confinement under carefully controlled conditions. The decay period can be thousands or hundreds of thousands of years for the long-lived actinide elements and certain fission products.

Radionuclides may be present in gaseous, liquid, or solid form. Solid wastes *per se* are not normally significant contaminants in man's environment until they become airborne (usually as particulates) or waterborne (by leaching). Consequently, environmental effects and regulatory limits are based primarily on concentrations in air and water.

FINDINGS AND CONCLUSIONS FOR RADIOACTIVE WASTES

A survey was made of the radioactive wastes to be expected for disposal in the year 1980, selected as the base year because the expected rapid growth of the nuclear industry will be well established at that time. Several years, probably until about 1980, will be required for detailed analysis of the hazards and disposal problems associated with radioactive wastes and development and implementation of disposal systems.

In this study, sources of radioactive waste are divided into three areas:

- production of nuclear electric power (i.e., those from the nuclear fuel cycle);
- miscellaneous private sources; and
- government sources, primarily the U.S. Atomic Energy Commission (AEC) and the Department of Defense (DOD).

The bulk of the radioactive wastes for disposal in 1980 will result from the commercial nuclear fuel cycle, as shown in Table 19. Government wastes, as discussed in the text, will be contributory, as will those from private sources. The AEC is currently conducting extensive studies for long-term management of both government- and industry-produced radioactive wastes.

The concept of national disposal sites or Federal repositories for radioactive wastes appears to be desirable because of the wastes' significantly high toxicity and the present impracticability of detoxification except by natural decay. At present a fully evaluated and technically acceptable concept for the ultimate disposal of radioactive wastes, regardless of classification, has not been developed. Present plans by the AEC seek construction of an interim storage facility as a repository for high-level wastes arising from the nuclear electric power industry. This facility is conceived as a 100-year solution to meet expected needs through the year 2000. By that time it is expected that an ultimate disposal technique will be evolved and accepted, possibly internationally.

A similar policy of interim storage for low-level radioactive wastes has been adopted for AEC sites but not at commercial burial sites. This policy, based on 20 year retrievable burial, will allow time for development of disposal technology. This is appropriate since the long-term toxicity of low-level wastes contaminated with actinides may equal or exceed that of high-level wastes. The technical problems associated with achieving interim storage solutions for both high- and low-level wastes are similar, except for heat generation considerations, and final solutions for both high- and low-level wastes may have much in common. Because methods for ultimate disposition of high- and

TABLE 19

SUMMARY OF RADIOACTIVE WASTES FOR DISPOSAL IN 1980

Item	Waste Stream Source	Form	Waste Category	Total Annual Curies	Total Annual Vol. or Wt.	Major Radioactive Elements
1	U milling tailings	sludge	low	3.3×10^4	3.6×10^{10} lbs	Ra, Th, Pb, Po
2	U conversion	solid	low	5.3×10^1	4.0×10^4 lbs	U, Th, Ra
3	Fuel fabrication	solid/liquid	low	1.3×10^6	1.6×10^4 ft^3	Pu, U
4a	Reactor control rods	solid	L-H	2.2×10^7	1.4×10^4 ft^3	Ag, Fe, H, Mn, Ni
b	Other reactor	solid/liquid	low	1.0×10^6	1.0×10^6 ft^3	H, Fe, Co, Ru, Cs
5a	Fuel reprocessing	solid/liquid	low	1.8×10^6	2.0×10^5 ft^3	Ce, Sr, Cs, Ru, Pu
b	Cladding hulls	solid	L-H	4.2×10^6	2.0×10^4 ft^3	Co, Ni, Fe, Mn, Sb
c	High level	solid	high	1.3×10^8	1.5×10^3 ft^3	Sr, Cs, Pm, Eu, Pu, Am, Cm
6	Miscellaneous private sources	solid/liquid	low	6×10^5	7×10^6 ft^3	Co, Sr, Pm, Cs, Pu, Am, Cm
7	Government wastes*	solid/liquid	L-H	-	2.7×10^6 ft^3	Fission product spectrum, Pu, Am, Cm, Co

Note: Waste sources in items 1 through 5 are from the commercial nuclear electric power industry.

*To be stored onsite

low-level radioactive wastes are still in the early exploratory phase, this chapter deals with the interim systems that are currently being designed for high-level wastes. In addition, a concept for a low-level radioactive waste processing and interim repository system is developed.

These interim repositories for radioactive wastes are essentially high-integrity modular, retrievable surface storage facilities of two major types based on the need for significant removal of radioactive decay heat: facilities for low-level wastes and facilities for high-level wastes.

The conceptual design for a candidate repository for high-level wastes has been derived from studies (through 1972*) of several concepts presently being evaluated for the AEC by the Atlantic Richfield Hanford Company. This facility (designed for the high-level wastes listed in Table 19 from private nuclear fuel reprocessing plants) consists basically of water storage basins in module configuration for storage of previously solidified and canned packages of high-level radioactive wastes under water to provide for cooling and shielding. An alternative scheme presently undergoing additional study is natural convection air-cooled storage of individual containers of solidified wastes. These wastes would be enclosed in sealed steel shielding casks in the open air in an arid climate area. The sealed steel canisters are 6 to 24 inches in diameter and up to 10 feet long. Treatment and processing (other than a small amount of decontamination and similar activities) will not be done at the high-level waste repository.

The sources for low-level wastes are uranium conversion, fuel fabrication, reactor control rods, other nuclear reactor wastes, fuel reprocessing cladding hulls, other fuel reprocessing wastes and miscellaneous private sources, as listed in Table 19. This will involve a total feed rate in 1980 of more than 10^7 cubic feet of solid waste and 1.2×10^8 gallons of liquid waste. The repositories will be capable of receiving and storing pretreated and packaged solid wastes for sorting, incinerating combustible wastes to ashes, and concentrating and drying liquid wastes to solids. The final annual volume of 700,000 cubic feet of solid waste will be packaged in sealed steel bins and stored in carefully designed compartmented warehouses. Producers of low-level radioactive wastes could decide whether to perform the pretreatment steps on the waste before shipment to the site. One type of storage building will have moderately thick shielding walls and another will have essentially no shielding for wastes.

---

*This is a continuing study and refinements and improvements should be expected. Significant revisions in the conceptual designs of the facilities have recently been published in the following reports:

ARH-2799, "Retrievable Surface Storage Facility-Water Basin Concept." Atlantic Richfield Hanford Company and Kaiser Engineers, June 1973.

ARH-2801, "Retrievable Surface Storage Facility-Sealed Storage Cask Concept." J. R. La Riviere, Atlantic Richfield Hanford Company, June 1973.

A preliminary capital cost estimate of $37 million for the high-level radioactive waste repository facilities was derived from studies by the Atlantic Richfield Hanford Company for design of a facility for the AEC, in which costs ranged from $20 to $40 million. Operating costs for 1980 were estimated at $3 million per year plus about $0.3 million per year for amortization. This cost information is detailed in Appendix S and all costs are in 1973 dollars.

Capital costs for treatment and storage facilities for low-level radioactive wastes were estimated at $44 million; operating costs (including amortization) were estimated at $6.9 million per year (all in 1973 dollars). The bases for these estimates are given in Appendix U.

Again in 1973 dollars, transportation costs for high-level wastes of $2.6 million for capital and $2.6 million per year for operating costs were projected, while $19 million for capital and $31 million per year for operating costs were estimated for low-level wastes. Details are given on pages 199-205. The high costs in these preliminary analyses suggest the need for further analysis of the waste management system, particularly for low-level radioactive wastes.

By the year 2000 the nuclear electric power industry is expected to grow by a factor of approximately eight from the anticipated level in 1980. With this factor in mind, and taking into account that the time lag for implementing concepts such as those developed here typically is six to eight years, major studies and decisions on radioactive waste management appear most appropriate.

At the present time Federal regulations permit burial of large quantities of low-level radioactive wastes directly in the soil at six commercially operated burial sites. In addition, the regulations permit burial of small quantities of radioactive wastes at the sites of the myriad of radioactive material users.

These practices and their proliferation should be thoroughly studied from the standpoint of long-term safety.*

Uranium mining and mill tailings (shown as Item 1 in Table 19) are a special case. These are very large quantities of impounded sludges which have low radioactivity levels. In essence, the volumes of these wastes are so large that it is impractical to handle them in the same manner as other radioactive wastes. Present AEC weapons materials sites such as Hanford, Washington and Savannah River, South Carolina are other special cases because of their long histories, large inventories of high- and low-level wastes, Federal jurisdictional positions, and high cost of decommissioning to levels permitting uncontrolled public access.

Other significant findings from this study are:

1. More technical information is generally known about the toxicity of radioactive wastes, their pathways for release to man's environment, and their management than any other category of wastes, but knowledge gaps still exist.

2. Regulations for handling and managing radioactive wastes are generally more stringent than for other wastes; a need for further improvement exists, however, particularly for long-lived low-level wastes.

3. Studies to determine the potential for sorting low-level wastes containing long-lived and toxic radionuclides at the low-level disposal sites should be undertaken to determine whether more suitable waste management schemes could result from these studies.

4. Gaseous radioactive wastes such as tritium and radiokrypton are not currently treated as waste products on a routine basis, and therefore they were not included in this study. However, they will be generated in the commercial nuclear

---

*A task force of the Conference on Radiation-Control has recently made similar recommendations. "Report of the Task Force on Radioactive Waste Management at Fifth Annual National Conference on Radiation Control," T. J. Cashman, task force chairman, Portland, Oregon, May 6-10, 1973.

electric power industry in increasing amounts in the future. Plans are being formulated for packaging of krypton. The need for their isolation from the environment is most likely. Studies of satisfactory treatment and disposal of these potential gaseous radioactive wastes should be continued to develop a viable system for their management.

BACKGROUND OF RADIOACTIVE WASTE MANAGEMENT POLICIES AND RADIATION PROTECTION REGULATIONS IN THE U.S.

The primary purpose of radiation protection is to restrict the radiation "dose" to people. "Dose," as defined in 10 CFR 20,[99] is the quantity of radiation absorbed per unit of mass by the body or by any portion of the body. The unit of dose is the rem, defined as the equivalent of a rad of x-ray, gamma, or beta radiation or 0.1 rad due to neutrons or high-energy protons. This is produced by exposure to a field of approximately one roentgen of x-ray or gamma radiation. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue.

The primary basis of dose is difficult to use directly in application. Consequently, secondary and lower degree controls are used in practice. The secondary basis is the radioactive burden in a critical body organ; other more easily used but still lower degree controls are body intake rate and concentrations of radionuclides in air, water, and food. Practical controls over the past years have been primarily those of maximum concentrations in air and water, with calculation of all other values from these. Recent trends, however, have been aiming toward controlling dose more directly.[100]

Overall Legislative History

The first organized attempt to control radiation dose was through the establishment in 1928 of the International X-Ray and Radium Protection Commission, which recommended maximum dose levels on an international basis.[101] In 1950, the Commission assumed its present form and name (The International Commission on Radiation Protection, ICRP).[102] The counterpart U.S. committee was established in 1929 as the Advisory Committee on X-Ray and Radium Protection.[103] The Advisory Committee was reorganized and named the National Committee on Radiation Protection (NCRP) in 1946, and in 1956 the words "and Measurements" were added to the title.

In the U.S., the Federal Radiation Council (FRC) was established by Congress in 1958 to advise the President on radiation protection matters and to provide guidance for all Federal agencies in the formulation of regulations for radiation protection. This function of the FRC was absorbed into the Environmental Protection Agency on the latter's creation in 1970.

The USAEC is responsible for regulation, implementation, and enforcement of radiation protection in nuclear facilities, and specified radionuclide disposal requirements and limits on radioactivity released in effluents. The Atomic Energy Act of 1946 assigned the responsibility for the radiation safety of workers and the public to the AEC. The Atomic Energy Act of 1954, as amended, emphasized the regulation of radioactive materials and established the framework for licensing the possession, production, and utilization of source, by-product, and special nuclear materials.

Prior to 1954, there was little need for regulation because all atomic energy activities were essentially under direct government control. The only exception, of course, was the private use of radioisotopes in medicine, industry, and agriculture.

In enacting this historic legislation, the Congress ended the government monopoly and thereby made it possible for individuals and organizations to own and operate nuclear reactors and other nuclear facilities, to possess and use fissionable materials, and in other ways to engage in atomic energy activities on a private, commercial basis. Parenthetically, it may be noted that under the Act private enterprise can engage in practically all atomic energy activities except the manufacture of atomic weapons.

In addition, the Atomic Energy Act of 1954 provided that, either directly or by transfer of authority to an agreement State, the AEC would be responsible for licensing and regulation of the handling and disposal of radioactive materials. When the States find it necessary to regulate, the criteria and standards they prescribe follow those developed by the AEC. Currently three commercial low-level radioactive waste disposal companies are operating under a license issued by a State which has an agreement with the AEC as authorized by Section 274 of the Atomic Energy Act of 1954, as amended.

In July of 1971 the AEC announced the establishment of the Division of Waste Management and Transportation. This division is responsible for long-term waste management, including the formalizing of objectives and policies related to the low-level and transuranic contaminated solid waste land burial at AEC sites and high-level waste storage in Federal repositories.

The National Environmental Policy Act of 1969 (Public Law 91-910) became effective in 1970. The law requires Federal agencies to evaluate the environmental impact of the facilities they license. As the agency responsible for licensing nuclear facilities, the AEC must prepare environmental impact statements for them.

General Dose and Effluent Considerations

Before World War II the chief concern with radioactive materials involved protection of workers against x-ray exposure. With the Manhattan Project an entirely new era in radiation protection was born and research began immediately to establish valid bases for acceptable doses of each of the many new isotopes produced by the newly discovered fission process.

The first semi-official regulation of 0.2 rem per day basic dose limit was applied to the occupational exposure of x-ray technicians and was provided by the ICRP in 1934. In 1936, the NCRP gave its first recommended maximum permissible dose (MPD) as a 0.1 rem per day (occupational).

In 1954, the ICRP and NCRP lowered the basic recommended MPD from 0.1 rem per day to 0.3 rem per week and recommended one-tenth this for nonoccupational groups. In 1957, the ICRP and NCRP recommended lowering the whole body MPD to 5 rem per year (occupational). This was the second and last change recommended by the NCRP, except for minor refinements, and marked the last time wherein basic differences existed in the recommendations of the two agencies.

Maximum permissible concentrations (MPC), more recently termed radionuclide concentration guides (RCG), for occupational exposure were published for the first time in 1953 by NCRP as National Bureau of Standards Handbook 52[104] and revised in 1959 as NBS Handbook 69.[103] The AEC first published MPC's (or RCG's) in air and water as part of its Code of Federal Regulations in 1957.[105] This was the first U.S. regulation which specifically gave concentration values for the public at large. The RCG's are based on continuous intake of air or water at the given concentrations. Occupational doses are based on 40 hours per week, or full-time exposure. The dose limits recommended by the ICRP and NCRP are for total exposure from all sources other than natural and medical sources.

The currently recommended dose limit from artificial radioactive sources (other than medical) to nonoccupational individuals is one-tenth of that to occupational workers.[99] The allowable dose to the various organs of the body of nonoccupational individuals is as follows:

Whole body, red bone marrow, gonads	0.5 rem per year
Bone, skin	3.0 rem per year
Thyroid, GI tract, kidney, most other body organs	1.5 rem per year

These values are for the maximum exposure to an individual; the average exposure for the population as a whole will meet the additional restriction of 5 rem per 30 years if the annual exposure does not exceed one-third of these values, or 0.17 rem per year for the whole body. Where there is a mixture of radionuclides in effluent air or water, the sum of the respective ratios of concentrations to concentration limits must not exceed 1. The regulations for nonoccupational exposures are based on concentrations at the site boundary, irrespective of the presence of more than one facility within the site.

A recently proposed Appendix I to 10 CFR 50 for light water reactors proposed that the radioactivity released to unrestricted areas be kept as low as practicable. The proposed numerical guides specify that effluents should not result in annual radiation exposure to the whole body or to any organ of an individual in excess of about five percent of that due to natural sources, or about five millirems.[106] The proposed regulation further states that the annual exposure to large population groups should generally be less than one percent of that received from natural radiation sources, or about one millirem per year. For gaseous effluents it proposes that an additional safety factor of 1,000 be applied for airborne particulate radionuclides with half-lives greater than eight days, to allow for buildup in the ecological chains. (For these radionuclides, the RCG's in 10 CFR 20 would then be divided by 100,000 for values at the site boundary.) The annual exposure rate from noble gases is to be kept below 10 mrem at the site boundary.

Limits proposed for liquid effluents would restrict the maximum emission from a reactor to no more than 5 curies per year or 2×10^{-8} μCi per cc in the undiluted plant effluent for all radionuclides except tritium, and 5×10^{-6} μCi per cc for tritium. The proposed regulation allows credit for dilution of airborne radionuclides with the air that flows through a light water reactor site, but does not allow credit for flows of natural bodies of water through the site.

The proposed Appendix I is for light water reactors only and specifically states that it does not apply to other nuclear facilities. However, it is believed that a similar regulation will eventually be imposed on other nuclear facilities. If the proposed Appendix I to 10 CFR 50 became a regulation for light water reactors as it now exists, the allowable dose to the general public would be reduced by factors of 100 to 100,000 compared to existing 10 CFR 20. While the final values for Appendix I are not yet established, indications are that they will be near those proposed,[107] and they are believed to be the best available current basis. Therefore, based on the above reasoning, the allowable effluent quantities and concentrations in proposed Appendix I are tentatively recommended in this study to apply to disposal sites.

Disposal or Long-Term Storage of Wastes

In essence, the regulations[99] state that all wastes which cannot be released to the air or water environment within the maximum permissible concentrations must be stored in a safe manner. Sections 20.301 through 20.305 of 10 CFR 20 apply specifically to waste disposal.

Other portions of Federal regulations that include waste management considerations are 10 CFR 30 (licensing of by-product material), 10 CFR 50 (Licensing of production and utilization facilities), 10 CFR 71 (packaging of radioactive material for transport), 10 CFR 100 (reactor site criteria), and 10 CFR 150 (exemptions and continued regulatory authority in agreement States under Section 274). A recent appendix to 10 CFR 50, Appendix F, limits the high-level liquid waste inventory of licensed fuel reprocessing plants to that processed in the prior five years. The liquid wastes must then be converted to an approved solid form within an additional five years and transported to a Federal repository for final disposition.

Storage of a limited quantity of radioactive wastes is permitted at the source site for extended indefinite periods in an accessible and retrievable fashion. "Disposal" of low and intermediate level radioactive wastes is permitted by near surface ground burial at AEC-State licensed disposal sites. In addition, small (curie) quantities of radioactive wastes are permitted to be buried at each source site under less rigid licensing requirements.

Administrative Arrangements

Over the years administrative arrangements have been developed which allow non-AEC producers of solid radioactive wastes to obtain burial services for their disposal. For a number of years certain AEC installations which had established facilities for burial of their own "on-site" wastes made their burial grounds available for disposal of shipments of solid wastes from industrial users of radioisotopes. During the 1950's an increasing volume of waste shipments came from private industries' AEC-licensed activities. In 1960 there were no commercially operated burial grounds for radioactive wastes in the United States and most of the licensees were using commercial sea disposal services provided by seven private firms.

In January 1960, the AEC announced that regional disposal sites for disposal of solid low-level packaged radioactive waste materials would be established, as needed, on State or Federal Government-owned land. The restriction of waste burial locations to government-owned lands was adopted to assure future custody and responsible protection of public health and safety during the long periods of time in which a hazard from radioactivity of the buried waste might exist.

In May 1963, the AEC withdrew from its program of providing low-level waste burial service to industry. This withdrawal was based upon the availability of commercial service from one company at two sites and evidence that at least two and perhaps more private companies expected to provide commercial facilities for low-level solid waste burial at other sites.

The background of administrative and operational developments for land disposal of solid wastes was reviewed by W. L. Lenneman.[108]

Federal Regulation and Control

It has been pointed out that directly or by transfer of authorization to one of the agreement States the AEC is responsible for licensing and regulating the handling and disposal of radioactive materials under jurisdiction prescribed by the Atomic Energy Act of 1954, as amended.

In judging the acceptability for licensing of a proposed facility for waste burial, the primary consideration is radiological health and safety. The quantity of radionuclides involved and the extent of possible dispersion to the environment must be evaluated and the acceptability of the potential radiation exposures that may result must be determined. As a basis for these judgments, evaluation studies of the proposed waste burial sites are necessary.[109]

The maintenance of safety in connection with radioactive waste burial depends primarily upon containment of the radionuclides within the burial site, and this depends upon the natural environment and operational procedures. As stated by Richardson,[110] the suitability of a site for land burial operations is completely dependent upon the ability of its environs to prevent the movement of radioactivity from point of burial to places where its presence might have adverse effects on man or his environment. However, such site evaluations are based on control of the movement of radioactivity for time periods of tens to perhaps hundreds of years, as contrasted by the possible needed control period of up to hundreds of thousands of years.

In the evaluation of a proposed or an existing operation for land burial of radioactive wastes all the conditions that might affect potential radiation exposures are considered. The application for a license must include information from which the adequacy of radiation protection can be judged and the site and associated operations can be appraised. The AEC Division of Materials Licensing has prepared an outline of licensing requirements for land burial of radioactive wastes.[111] Essentially the same information is required by the agreement of the States since, in accepting the transfer of the material licensing functions from the AEC, they have agreed to keep their regulations and requirements compatible with those of the AEC.[112]

The licensing requirements specify that the application must include information regarding: 1) the amount of by-product material, source material and special nuclear material to be possessed at any one time; 2) qualifications of the applicant and members of his staff to engage in the proposed activities, including specialized training and experience in handling radioactive materials and dealing with radiation problems, and a description of the radiation detection instruments that will be available; 3) the radiation protection procedures, including emergency procedures for each phase of the program; and 4) a description of the site and facilities that will be used for storage, processing and disposal of the radioactive wastes. Maps and drawings of the proposed facilities and a description of the buildings and equipment to be used are required. The AEC's Rules and Regulations, which establish radiation exposure standards and precautionary measures, specify that the licensee must comply with the regulations, and require that standard operating procedures be based on the regulatory requirements.

Licensing requirements also call for detailed information concerning geology, hydrology of the site, groundwater conditions in relation to burial methods and possible movement of radioactive materials on or away from the site, the use of groundwater and surface water at the site and in adjacent areas, geochemical characteristics of the soil in which the burial trenches are excavated, and specific plans for monitoring soils and water. Monitoring methods are to take into account the data and knowledge of the hydrogeologic system determined by geology and by hydrologic evaluation of the site and its environs. Waste disposal licensees must conduct their transportation of radioactive materials in accordance with applicable regulations of the Department of Transportation[113] and other Federal agencies having jurisdiction; and licensees are subject to State and local requirements regarding highway safety handling of radiation emergencies and other problems which may be involved.

At the conference on the disposal of radioactive wastes held in Monaco on November 16-21, 1959, Rogers of the AEC gave a paper which explained AEC licensing procedures, including approval of the conditions of radioactive waste burial.[114]

Federal regulations call for radiation safety plans, manuals of operational and health physics procedures, and adequate, up-to-date systems of routine forms, daily records and formal reports. With revision as needed and with follow-up through agency inspections and joint work on special problems, the licensing agency and the licensee are to maintain effective safety measures. A radiation safety plan is approved as a part of the licensing action between the licensing agency and the licensee; radiation safety committees of qualified company officials are to be formally established and a continuing program of personnel training in radiation control is to be conducted by the licensee.

Radiation monitoring programs are to be conducted as required by the licensees and the radiation control regulations which they embrace. The extent and frequency of the monitoring activities can reflect local conditions and agency and company policies. The licensing agency is to be informed of these activities by operations reports and by visits and inspections of records at the site.

State Regulation and Control

An increasing number of States have entered into agreements with the AEC by which most of the direct responsibility for regulation and control of AEC licensed materials is transferred to the agreement States, including the disposal of solid radioactive wastes.[115] Disposal of high-level solid wastes, however, remains under AEC jurisdiction.

The licensee's burial facilities and related waste packaging, transportation and handling operations are of direct concern to all the States that may be affected because of health and safety considerations. Consequently, the commercial waste burial facilities, available to all producers of solid radioactive wastes in the United States, are subject to site approval and periodic inspections by the AEC or by the agreement State in which a facility is located. It is stipulated in the agreements that the licensing procedures and criteria of the agreement States be compatible with those of the AEC. Based on compatibility of rules, regulations and procedures, the AEC and the

States have developed reciprocity in recognition of some licenses issued by the AEC and by the agreement of the States. This reciprocity between States does not, however, apply to the operation of a permanent installation such as a waste disposal facility.

These present Federal and State regulations permit the burial of low-level radioactive wastes in their containers directly in the soil at the State licensed repositories. Such practices should be analyzed in detail with respect to the very long-term hazard of the waste.

It should be noted that all States have authority to enact laws and to adopt State regulations as considered necessary to protect the health and safety of the population. Under this authority, a nonagreement State can develop its State system of evaluation and control of any potential health hazards, including radioactive wastes and other sources of ionizing radiation.[116-131] An examination of various State regulations indicates that significant State individualism may be exercised in low-level radioactive waste burial only in organizational and nonradiological aspects of the operations.

Shown in Table 20 is a general summary of State regulations other than special provisions for each site. Uniform treatment of the requirements of all States beyond the points included in the table and in the discussion above would require much more detailed analysis.

RADIOACTIVE WASTES AND A NATIONAL SYSTEM FOR HAZARDOUS WASTE MANAGEMENT

From the outset of the Manhattan Project, the potential hazards of radioactive wastes were generally well recognized and methods were adopted to limit their release to man's environment. The quantities of radioactive wastes resulting from the generation of electrical power by nuclear fission will increase by approximately two orders of magnitude by the year 2000. As the quantities and number of sources increase at the very high rates projected, there will be an increased need for controlled disposal techniques in a national system designed to assure the health and safety of the public and the protection of the environment through the isolation of radioactive wastes. This assurance of isolation is required for the continued development of the nuclear power industry in its effort to meet the nation's energy needs.

TABLE 20

STATE REGULATIONS FOR RADIOACTIVE WASTE DISPOSAL

Above Ground Possession Limits	Special nuclear material - less than critical mass Source materials Byproduct materials	(100s grams)* (1000s pounds) (1000s curies)
Acceptable Physical Forms	Solid or liquid**	
Burial Technique	Buried as shipped under DOT regulations in surface burial trenches ≈ 20 ft deep	
Radiation Monitoring Requirements	Equipment - contamination control and biological exposure control Environmental - environmental impact and biological exposure evaluation Personnel - personnel exposure evaluation and reporting	
Non-radioactive Monitoring Requirements	State implementation of NEPA, Council on Environmental Quality and Clean Air Act provision minimums	
Site Requirements	Bottoms of trenches should be at least 5 ft above the water table whenever possible	

---

* Units for regulated quantities.

** Liquids are fixed prior to burial.

Note: Special nuclear material refers to U-233, U-235, Pu-239; source material refers to natural or depleted uranium and natural thorium; byproduct materials refers to fission products.

CATEGORIES OF RADIOACTIVE WASTES IN A NATIONAL DISPOSAL SYSTEM

The many types of radioactive wastes can be categorized by their heat generation rates, levels of radioactivity, required terms of storage for decay to radiologically insignificant levels, and physical and chemical forms. Because most types of radioactive wastes require very careful control during storage for long periods (at least hundreds of years), the storage systems for most types of wastes can be similar.*

The one characteristic which impacts design concepts significantly is the inherent heat generation rate within the waste. Based upon this characteristic two categories of waste were established for this report:

1. high-level wastes (those which have heat generation rates at or above the tentatively selected value of 0.1 watts per cubic foot); and

2. low-level wastes (everything else).

High-level wastes require either active or passive heat removal systems and very heavy radiation shielding. Low-level wastes do not require a heat removal system but do require a range of shielding from almost none to moderately heavy. A plutonium content of about five grams per cubic foot in low-level waste would not exceed a heat evolution limit of 0.1 watts per cubic foot.[132] This heat evolution rate is a conservative value to keep the temperatures of wastes well below the ignition point of paper.

The definition of high-level and low-level radioactive wastes used for the purpose of this study is only one of many possible definitions. For example, low-level radioactive wastes are commonly defined at AEC sites as those that may be safely discharged into man's environment; all other wastes are considered high-level or intermediate-level wastes. In the nuclear fuel reprocessing industry, only the concentrated wastes from the first cycle of solvent extraction are known as high-level wastes; all others are considered to be low-level, regardless of their potential toxicity.

---

*Extended studies beyond the scope of this one may be considered wherein the incentives would be evaluated for sorting and using a larger variety of waste storage disposal techniques. In particular, a different philosophy of waste storage/disposal might be considered for wastes whose toxicity becomes unimportant after a few years or a few tens of years.

Potential Radiological Toxicities Associated With Radioactive Wastes

Because the potential toxicity of radioactive wastes is due to radioactive decay, the toxicity varies significantly with storage time through hundreds of thousands of years. Characterization of radioactive wastes in terms of curies at the time of discharge then becomes meaningless in relation to radiological safety. Information presented in Appendix O shows that toxicity is a function of aging time after reactor discharge[133-136] and this factor can be predicted by the use of toxicity indexes. In general, the crucial aging times for most (but not all) fission products are less than 1,000 years, after which actinides continue to be important.

SOURCES OF RADIOACTIVE WASTES

The first large source of radioactive wastes was the massive defense effort initiated at the beginning of World War II with the Manhattan Project for developing and manufacturing nuclear weapons. At the end of the war nuclear energy and associated radioactive constituents were placed under civilian control of the U.S. Atomic Energy Commission by the Atomic Energy Act of 1946. Changes in this Act in the 1950s emphasized peaceful as well as military uses of atomic energy and permitted private industry to enter the nuclear field in a variety of areas, including the development of nuclear reactors for the generation of electrical power.

Although generation of radioactive wastes as a result of defense efforts continues, it is expected that future quantities will increase primarily from commercial nuclear electrical power. It is estimated that over 20 percent of the total electrical generating capacity in the United States will be nuclear in 1980, and in fact nuclear power is one of the fastest growing industries in the country.

In summary, the primary source of radioactive wastes in the future will be a rapidly growing commercial nuclear power industry. The second major source will be the Federal government, specifically the Atomic Energy Commission (AEC), where large inventories of wastes have been generated from past weapons production and current production rates are still significant. In addition, a small amount of radioactive wastes will come from a host of miscellaneous medical, research and development, and industrial applications.

For this study, the amount of radioactive wastes which will be accumulated through 1980 was calculated and used as the base need for disposal capability. The year 1980 was selected as the base year because the expected rapid growth of the nuclear industry will be well established by that time. The interim period will be required for detailed analysis of the hazards and disposal problems associated with radioactive wastes and development and implementation of systems.

Descriptions of the radioactive wastes expected to be present in the year 1980 have been developed from internal Battelle-Northwest searches and from previous studies by Booz-Allen Applied Research and TRW Systems, Inc. The most complete information obtained was that for the nuclear power economy. Government wastes were also researched, except when weapons production classification considerations precluded use of exact data. This information base is felt to be adequate for the purposes of this study. Projections concerning wastes from these sources are discussed in the following sections.

Either of two approaches can be used for estimating radioactive waste inventories. One method involves finding wastes and inventorying their bulk, their radionuclide concentrations and total content, and their chemical content. The second approach entails consideration of the primary sources (of which there are only two kinds, mining and irradiation in nuclear reactors) and the use of recovery factors that apply to the secondary processing of the materials produced.

The first approach is desirable for determining the state of dilution of the radionuclides and the chemical composition of the wastes to be treated. It is very poor, however, for estimating the total quantity of radionuclides in the wastes. Because of the wide variety of waste forms, physical localities, local inventory methods or lack of them, difficulty in measurement of quantities in heterogeneous distributions at low concentrations, decay of radionuclides after inventory, and secrecy of classification, a true picture of the total quantity and kinds of nuclides is very difficult to achieve. Therefore, an incomplete picture of the total potential toxicity to the environment is always the result.

In the second method the amount of radioactive material generated in reactors is estimated by computer codes which model the dynamics of the nuclear industry. This technique is so highly developed that predictions of inventories of all the radionuclides from nuclear power through the year 2000 have been made. Furthermore, the recovery factors from each process by which the radionuclides are treated have been estimated within error limits of about 30 percent. Once the total radionuclides in the wastes from all the generators of radioactivity are estimated, the potential toxicity of each phase of the operation can be determined. This approach gives little data on the chemical environment of the waste radionuclides and is also hampered by secrecy in military weapons production.

An accurate picture of the radionuclide inventories and their dispersion can be assured only when the answers obtained by using the two approaches converge.

RADIOACTIVE WASTES FROM THE COMMERCIAL NUCLEAR POWER INDUSTRY

As indicated earlier, it is expected that in the future the largest quantities of radioactive wastes will result from the operation of nuclear reactors for electrical power and the associated nuclear fuel cycle. In addition to nuclear fission in reactors, major fuel cycle activities include uranium mining and milling; uranium purification and conversion to uranium hexafluoride; uranium enrichment; uranium and plutonium conversion to oxide and fabrication into fuel elements; and after reactor exposure, reprocessing of spent fuel elements. Except for enrichment, fuel cycle activities are private (nongovernment) industrial activities.

Since uranium is radioactive, all activities of the fuel cycle produce radioactive wastes to some degree. However, as in the case of plutonium production, it is the generation of fission products within the fuel assemblies and the subsequent chemical processing of these fuel elements that results in fission product or high-level waste streams. In the case of the power industry, the chemical reprocessing recovers unused uranium and the plutonium that is produced. In addition, fuel fabrication activities which use the recovered plutonium will be significant sources of transuranic contaminated wastes, i.e., wastes contaminated with long half-lived and highly toxic actinide radionuclides.

The Nuclear Fuel Services Facility (NFS), West Valley, New York, has been the only operating commercial reprocessing plant. To date, high-level waste solutions accumulated at NFS have been stored in underground storage tanks. The Midwest Fuel Recovery Plant (MFRP) of the General Electric Company near Morris, Illinois, should be operating during the latter half of 1973. Also, the Barnwell Nuclear Fuel Plant (BNFP) of the Allied Gulf Nuclear Fuel Services Company is expected to be operable in 1975.

The quantities of wastes which will arise from the U.S. commercial nuclear power industry in 1980 were projected for the following categories: (a) radioactive constituents; (b) production quantities; (c) geographic distribution; and (d) treatment processes for the gaseous, liquid, and solid waste streams associated with mining, milling, conversion, enrichment, fuel fabrication, irradiation, and reprocessing. The information was then used to characterize prospective waste streams based upon current and proposed Federal regulations for allowable releases of radionuclides to the environment. All quantities in excess of these allowable releases would require disposal in a fashion compatible with a national system for hazardous waste management. With these bases, almost all of the wastes from the commercial nuclear power industry will require disposal within the concept of the national system.

QUANTITIES, CONSTITUENTS, DISTRIBUTION

Table 21 summarizes information concerning the total radioactivity (curies per year) and production quantities estimated for the various waste streams while Table 22 summarizes information related to the geographic distribution of the waste sources. Detailed information from which Table 21 was taken is given in Appendix C. Due to a lack of available quantitative information, waste streams which could result from the decommissioning of plants were neglected when developing information about production quantities. The U-235 depleted tails associated with nuclear fuel enrichment were assumed to be a stored product which will eventually be reused in the nuclear fuel cycle. In several instances the quantity of nonradioactive materials associated with a particular waste stream remains undefined. In these instances, therefore, as shown in Table 21, production quantity was determined from isotopic specific activities and annual production is for a "pure" or radioactive waste stream without nonradioactive constituents. It was also assumed that for Table 21 the radioactivity of fuel reprocessing high-level wastes and fuel cladding hulls would be allowed to decay for five years prior to the disposal of these two waste streams as solids. This basis was selected to be consistent with 10 CFR 50, Appendix F.

Additional assumptions and details are presented in Appendices C and D along with lists of radioactive constituents and treatment processes for individual waste streams. Except for fuel reprocessing wastes, information was developed primarily from reference 137, a study of quantities of radionuclide wastes from the power reactor industry that was based on combinations of available data and material balances. Information related to the reprocessing industry, especially projections for high-level wastes and actinide constituents, was obtained primarily from references 134, 138, and 139.

PROSPECTIVE WASTES FROM THE NUCLEAR FUEL CYCLE

Descriptions of prospective wastes from the nuclear fuel cycle for consideration in a national hazardous waste management program are summarized in Table 23. The basis used for the selection of solid wastes from the inventories presented on

TABLE 21

SUMMARY OF RADIOACTIVE WASTES FROM COMMERCIAL NUCLEAR POWER INDUSTRY TO BE PRODUCED IN 1980

Appendix Work Sheet	Waste Stream	Total Annual Curies	Annual Production	Remarks
-	Mining, gaseous	-	-	Radon release from mines undefined to date
-	Mining, liquid	-	-	Assumed zero
-	Mining, solid	-	-	Assumed zero
2a	Milling, gaseous	$9X10^3$	$1.3X10^{-4}$ lbs$^{(a)}$	Assumed all Rn-222, particulate concentration Unknown
2b	Milling, liquid	1.1	$4.0X10^9$ lbs	Aqueous effluents from tailing ponds
2c	Milling, solid	$3.4X10^4$	$3.6X10^{10}$ lbs	Mill tailings, abandoned piles stabilized against "release"
-	Conversion, gaseous	-	-	Assumed zero, radon released during milling and buildup minimal
3b	Conversion, liquid	0.7	$1.0X10^{10}$ lbs	Off-gas scrubber solution to waterways via limestone beds
3c	Conversion, solid	$5.3X10^1$	$4.0X10^4$ lbs$^{(a)}$	Impounded solids arising from water treatment
4a	Enrichment, gaseous	5.310^{-1}	$1.5X10^3$ lbs$^{(a)}$	Airborne wastes that leak from process equipment and escape treatment
4b	Enrichment, liquid	4.1	$1.2X10^4$ lbs$^{(a)}$	Liquid wastes, treated for release to waterways

(a) Production estimated from isotopic specific activity of U-238.

TABLE 21 (continued)

Appendix Work Sheet	Waste Stream	Total Annual Curies	Annual Production	Remarks
-	Enrichment, solid	-	-	Tails uranium assumed to be a stored product
5a	Fuel fab., gaseous	8.5×10^{-1}	1.0×10^{3} lbs[(a)]	Primarily particulate uranium
5b	Fuel fab., liquid	2.0×10^{1}	3.5×10^{8} lbs	Supernate resulting from treatment of aqueous wastes
5c	Fuel fab., solid	1.3×10^{6}	1.6×10^{4} ft^3	Conglomerate solids, primarily paper and plastic
6a	Irradiation, gaseous	2.0×10^{7}	7.4×10^{-2} lbs[(a)]	Stack discharge, most of activity due to noble gases
6b	Irradiation, liquid	8.0×10^{5}	1.8×10^{-1} lbs[(a)]	Tritium activity - 8×10^{5} Ci; Other isotopes ~ 10^{3} Ci
6c	Irradiation, solid	2.2×10^{7}	1.0×10^{6} ft^3	7×10^{5} ft^3 trash; 1.4×10^{4} ft^3 activated components including 1.3×10^{7} Ci of Ag-110 and 0.8×10^{7} Ci of Fe-55 in Control rods; 3×10^{5} ft^3 "solidified" liquids
7a	Reprocessing, gaseous	2.7×10^{7}	8.0×10^{9} lbs	Stack discharge including 2.5×10^{7} Ci of Kr-85 and 1.6×10^{6} Ci of tritium
7b	Reprocessing, liquid (low level)	3.0×10^{4}	2.7×10^{8} lbs	Tritium activity - 3×10^{4} Ci, Other isotopes ~ 2×10^{2} Ci

TABLE 21 (continued)

Appendix Work Sheet	Waste Stream	Total Annual Curies	Annual Production	Remarks
7c	Reprocessing, liquid (high level)	$6.6X10^9$	$8.8X10^5$ gal	Information only, aqueous nitrate solution that would be released as a solid stream in 1985
7d,7e	Reprocessing, solid	$1.3X10^8$	$2.5X10^5$ ft^3	$1.5X10^3$ ft^3 and $1.3X10^8$ Ci hi-level solids produced in 1975 with 5 yr of decay; $2.0X10^4$ ft^3 and $4.2X10^6$ Ci in cladding hulls with 5 yr of decay; $2.3X10^5$ ft^3 and $1.8X10^6$ Ci in trash, "solidified" liquids, etc.

TABLE 22

SUMMARY OF GEOGRAPHIC DISTRIBUTION OF RADIOACTIVE WASTES FROM COMMERCIAL NUCLEAR POWER INDUSTRY IN 1980

(Fraction of Radioactivity in each Region, $T \leq 0.05$)

	No. of Individual Source Sites	New England	Mid Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	West	Mountain
Mining	>200	-	-	-	-	-	-	T	-	1.0
Milling	20	-	-	-	T	-	-	0.1	T	0.9
Conversion	2	-	-	0.6	-	-	-	0.4	-	-
Enriching	3	-	-	0.2	-	-	0.8	-	-	-
Fuel Fabrication	13	0.1	0.2	-	-	0.3	0.1	0.1	0.2	-
Irradiation	125	0.1	0.2	0.2	T	0.3	0.1	T	T	0.1
Reprocessing	3	-	0.3	0.1	-	0.6	-	-	-	-

TABLE 23

PROSPECTIVE WASTE STREAMS FOR NATIONAL DISPOSAL SITES FROM COMMERCIAL NUCLEAR POWER INDUSTRY IN 1980

Waste Stream	Total Annual Curies	Annual Production	Curies of Radioactive Constituents
Milling, Solid - Mill Tailings	$3.4X10^{4}$	$3.6X10^{10}$ lbs	Ra 226, $9X10^{3}$; Th 230, $6X10^{3}$; Pb 210, $2X10^{3}$; Po 210, $2X10^{3}$
Conversion, Solid - Impounded Drummed Solids	$5.3X10^{1}$	$4.0X10^{4}$ lbs$^{(a)}$	U 238, $6X10^{0}$; Ra 226, $1.6X10^{0}$; Th 230, $4.6X10^{1}$
Fuel Fab., Solid - Conglomerate Solids, and Solidified Liquids$^{(b)}$	$1.3X10^{6}$	$1.6X10^{4}$ ft^{3}	Pu 241, $1.3X10^{6}$; Pu 240, $4.8X10^{3}$; Pu 239, $3.9X10^{3}$; Pu 238, $1.9X10^{4}$
Irradiation, Solid - Control Rods	$2.2X10^{7}$	$1.4X10^{4}$ ft^{3}	Major Constituents: Ag 110, $1.3X10^{7}$; Fe 55, $8X10^{6}$; Ag 108, $4X10^{5}$; H3, $3.4X10^{5}$; Mn 54, $2.5X10^{5}$; Ni 59, $1.5X10^{5}$
Irradiation, Solid - Conglomerate Solids and Solidified Liquids$^{(b)}$	$1.0X10^{6}$	$1.0X10^{6}$ ft^{3}	Major Constituents: H 3, $8.0X10^{5}$; Fe 55, $4.5X10^{4}$; Co 60, $1.7X10^{4}$; Ru 106, $8X10^{4}$; Cs 134, $1.1X10^{4}$; Cs 137, $4.1X10^{4}$

West would be traveling in fewer restricted speed zones, so the maximum distance is greater than in the East. Some of the regions do not contain an industrial waste production center, but such centers are found in surrounding regions. No region was permited to cross any major physiographic barrier. Figure 35 shows that the regional divisions are smaller in the East than in the West.

COUNTY SUBDIVISIONS

The problems associated with choosing the final areal subdivisions to which the site evaluation criteria would be applied have been described: namely, the data constraints and unmanageability of very small areas, and the lack of specificity and data variability for large areas. Examining the information demands and suitability for satisfying site criteria needs, it can be seen that few of the parameters show sharp changes at political boundaries (townships, counties, states); rather, there is a blending or gradation in the values of most parameters over fairly large areas (e.g., climate, soils, vegetation). Thus, adjacent moderate-sized subdivisions will have identical values for many of the parameters considered in ranking sites.

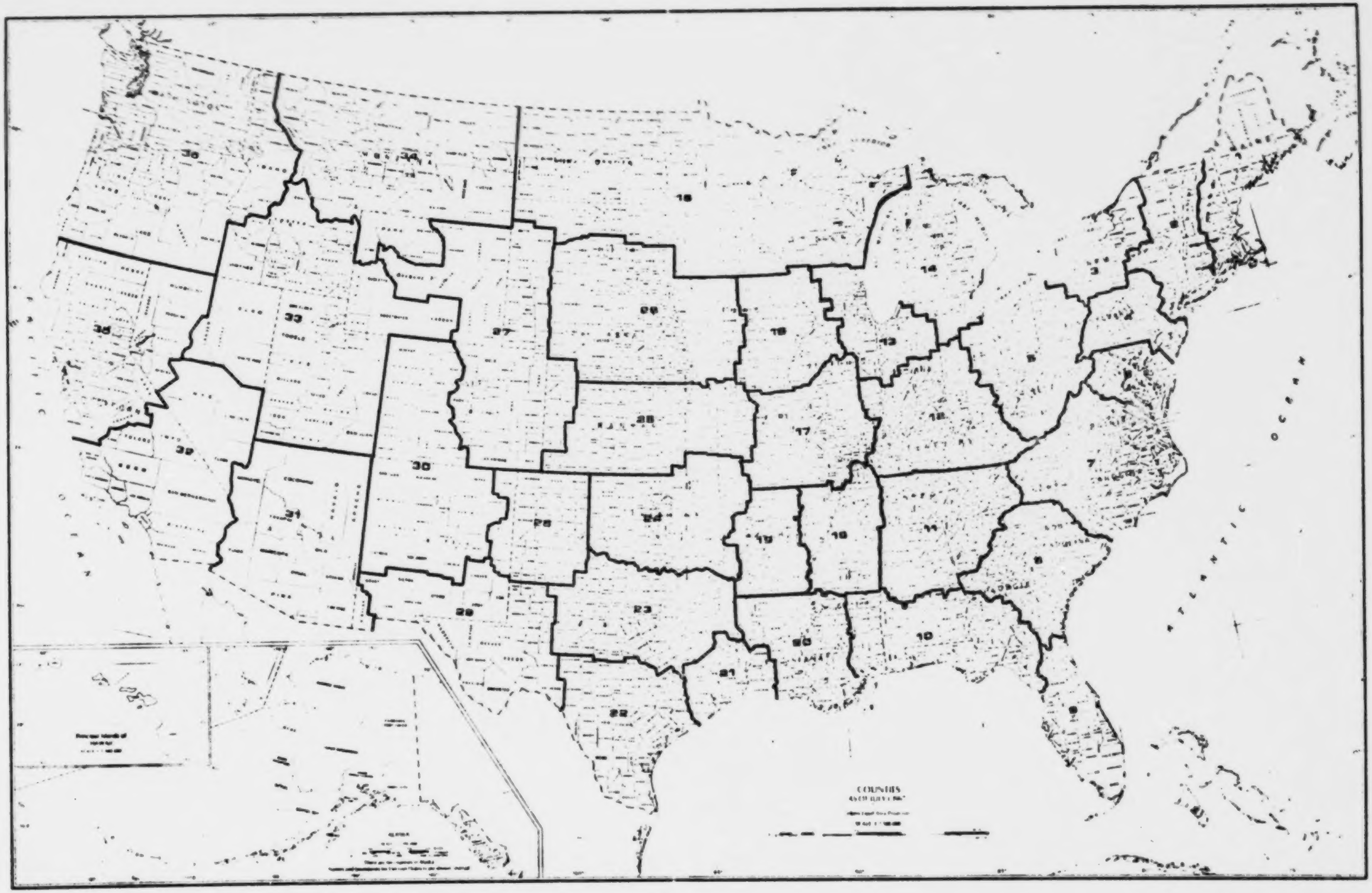
If one tries to discriminate or interpolate these data into finer detail, the data sources described earlier (National Atlas, etc.) become no longer applicable, and the information needs fall back upon the many nonuniform literature sources that present extreme complexities in the analysis sequence. Ideally, a compendium of current and uniform data applicable to all the evaluation parameters by States, or more desirably by counties, would best satisfy the nationwide site selection information needs--a 48 or 3,050-volume set of Site Selection Information Encyclopedia. Such volumes do not exist, of course, nor is it probable that any will ever be assembled.

Individual publications on counties or smaller areas usually created for industrial promotion present information required for site analysis with varying degrees of detail and accuracy. Some of these, prepared at considerable expense and effort, are quite accurate and reflect the expertise that has gone into their preparation. Others are shallow and obviously inaccurate in many areas, reflecting the public relations approach more than scientific validity. In any case, too few adequate publications of this type exist to form a competent base for nationwide site selection analysis.

Lack of an existing uniform information base between the National Atlas type of data source and the many detailed and varied reports on individual areas and criterion parameters dictated

FIGURE 35

SITE SELECTION REGIONS


36
34
16
35
33
27
26
15
14
13
6
3
2
32
25
17
12
5
4
30
31
28
24
19
18
11
7
8
29
23
20
10
21
22
9
ATLANTIC OCEAN
COUNTIES

that the final subdivision be of a size that one could confidently evaluate from the information presented in the nationwide data sources. These sources, in some instances, could be supplemented by more detailed consistent nationwide data available from publications on specific subject areas (e.g., rail transportation networks in the United States) and from easily accessible agency record files (e.g., The National Weather Records Center).

The finest subdivision available for publications such as the National Atlas is the county. Transparent overlays are available for all of the topical maps in the Atlas. Furthermore, the county system of division (3,050) is nearly ideal for evaluation and matrix manageability. It was clearly understood that using an area so much larger than an actual site area would not identify specific sites. Rather it was recognized that the analysis would define those counties where the general existing conditions would be most or least suitable for sites. This could also be expressed as the relative number of potential sites per county.

The next phase of the site selection process involved appraising each region county-by-county, using the previously discussed criteria with appropriately assigned rankings and constructing a weighting system for the criteria so that they could be combined to arrive at a total rating for each county.

RANKING AND WEIGHING SYSTEMS--DEVELOPMENT AND APPLICATION

The task of ranking sites (in this case, counties) according to their fulfillment of desired criteria is closely related to the amount of detailed information available. A fairly precise ranking, 1-10 for example, requires considerably detailed information. For the amount of detailed information available to this study a site ranking (or value function) of 1-5 was deemed appropriate for each criteria area.

Thus, the ranking process consisted of an analysis of each county by each professional, who then assigned a value of 1-5 to the combined parameters in his particular criterion area. The highest ranking of 5 was assigned to those counties where conditions best satisfied the criteria. Conversely, a ranking value of 1 was assigned to counties where conditions were least satisfactory. Values between 1 and 5 reflect the degree to which the parameters of concern approach optimum conditions. As discussed previously, a value of 0 was reserved as a "flag" to denote potential critical concerns in counties relative to the difficult-to-assess human environment and resources utilization criterion category.

Following the assignment of a ranking to each county in each criterion area, these values had to be summed to reflect the relative importance (weight) of each criterion area in determining the overall county rating. The weighted value-function approach was deemed the most applicable method for this phase of the site selection analysis.

The weighted value-function approach requires the development of two factors for each parameter under consideration--the weighting factor and the value function (ranking). The value function is based on a scientific or technological judgment by knowledgeable professionals of the suitability of each site with respect to the criteria. The weighting factor, on the other hand, is subjective and involves the opinion of individuals or groups of individuals as to the relative importance of each criterion area. The individuals supplying the opinions may or may not be knowledgeable in these areas. The value function makes it possible to compare alternative sites in terms of their effect on a particular siting parameter. However, it is not possible to sum all of the effects for an overall evaluation of each alternative site without weighting factors; that is, it is not possible to technologically state that air quality is more important than water quality, or preservation of aquatic biota is more important than avoidance of visual intrusions on the landscape. Since individual opinions may differ as to the importance of each parameter, different groups may produce different sets of weighting factors which, in turn, could produce different rankings of alternative sites. However, if the groups are large enough, the sets of weighting factors should not be too different.

The weighting factors used in this study demonstrate one method for obtaining the factors. They were statistically derived from the individual responses of ten professionals working on the site selection study. Further explanation of the weighting determination technique is presented in Appendix M. The sum of weighting factors equaled 100, and the product of the weighting factor (0 to 100) and ranking value (0 to 5) for each siting criteria resulted in a number which can be summed over all of the siting criteria for a given county. This summation for each county represents a quantitative rating which can then be numerically compared against a perfect score (500) and against the other counties within the region. Additionally, the weighting assigned to the earth sciences criteria was distributed among the four subcategories using a procedure identical to that used for weighting the major criterion areas only the earth sciences professionals participated in this determination. These subcategory weightings varied slightly between some regions, depending upon the relative importance attached to them by the evaluators.

The weightings determined by the team of professional participants follow.

Earth Sciences (Physical/Chemical)		31
Geology	7	
Hydrology	8	
Climatology	10	
Soils	6	
Transportion		28
Human Environment and Resource Utilization		23
Ecology		18

These final values were the result of a second iteration of the weighting procedure and differ by only 1 to 2 points from the values arrived at in the initial weighting. Table A-94 in Appendix M is a tabulated print-out showing the counties within each region, their respective rankings in each criterion area, the weighting factors for each criterion area, and the summation of the products of rankings and weightings. The tabulation is presented in descending order from highest to lowest ranked county within a region.

The results of the county-by-county ranking process confirmed some anticipated relationships. For example, several groups of adjacent and similarly-ranked counties maintained these rankings throughout the summation process and showed similarity in the overall rating values, all being either fairly high or low on the final rating list. This happened because, as discussed earlier, the parameters considered do not change abruptly nor do they recognize political boundaries; climate is the most obvious case. In general, the higher-ranked counties have the lowest population and overall development. This reflects to some degree that the criteria tend to favor areas less attractive for human habitation for many of the same reasons that they are sparsely inhabited or developed. For example, inadequate water supply is generally a favorable condition for siting since there is less potential for polluting a major aquifer or stream. Poor agricultural soils, if they are calcareous, might be favorable for removing spilled hazardous materials by soil-sorption mechanisms.

In addition, several of the criteria areas relate closely to population densities, and the rankings reflect direct proportional or inverse relationships. Croplands, which ranked high in the ecology category (lack of species diversity), also usually ranked relatively high in the human environment category (low population density, fewer people exposed to potential accidents). High transportation rankings (good road and rail networks) tended to correspond with low human environment rankings (high population densities). Such relationships were less evident in the earth sciences category. However, on considerations of climatic extremes (hot and dry or cold and wet), there were two inverse relationships with the human environment. Both extremes resulted in low population densities; however, hot and dry conditions are favorable site characteristics (particularly for disposal/storage sites), and the cold and wet conditions are climatically unfavorable conditions.

In summary, the ranking and weighting procedure developed for a nationwide survey of sites results in a rating system which should be a useful base for further detailed site investigations within the defined regions. The techniques similar to those used in the ranking process have been utilized successfully in many industries (e.g., siting nuclear power plants), although in most of those instances the criteria were initially more completely defined through experience, guidelines or regulations. Criteria for this study had to be developed from conceptual plant designs with largely unknown risk probability, acceptability values, and other factors that only operational experience will quantify; nevertheless, the evaluation technique is sound.

CHARACTERISTICS AND LOCATIONS OF EXISTING AND POTENTIAL SITES

The desirable and undesirable characteristics presented earlier are discussed below for each criterion area. A summation of the major characteristics was made to describe an "optimum" processing or storage/disposal site. In general, the characteristics for the two types of sites are the same; the disposal/storage site would have more rigid isolation and less rigid transportation features than the waste processing site.

- Location of the site should prevent any significant, predictable leaching from accidental waste spills, planned effluent disposal, or planned hazardous waste treatment products storage to shallow unconfined aquifers either in use or of potential use.
- The base of the treatment plant site should be at least twenty feet above the high water table.
- The base of the primary storage site should be at least one hundred feet above the high water table.
- The site should be located where no significant hydrologic surface or subsurface connection exists with standing or flowing surface water.

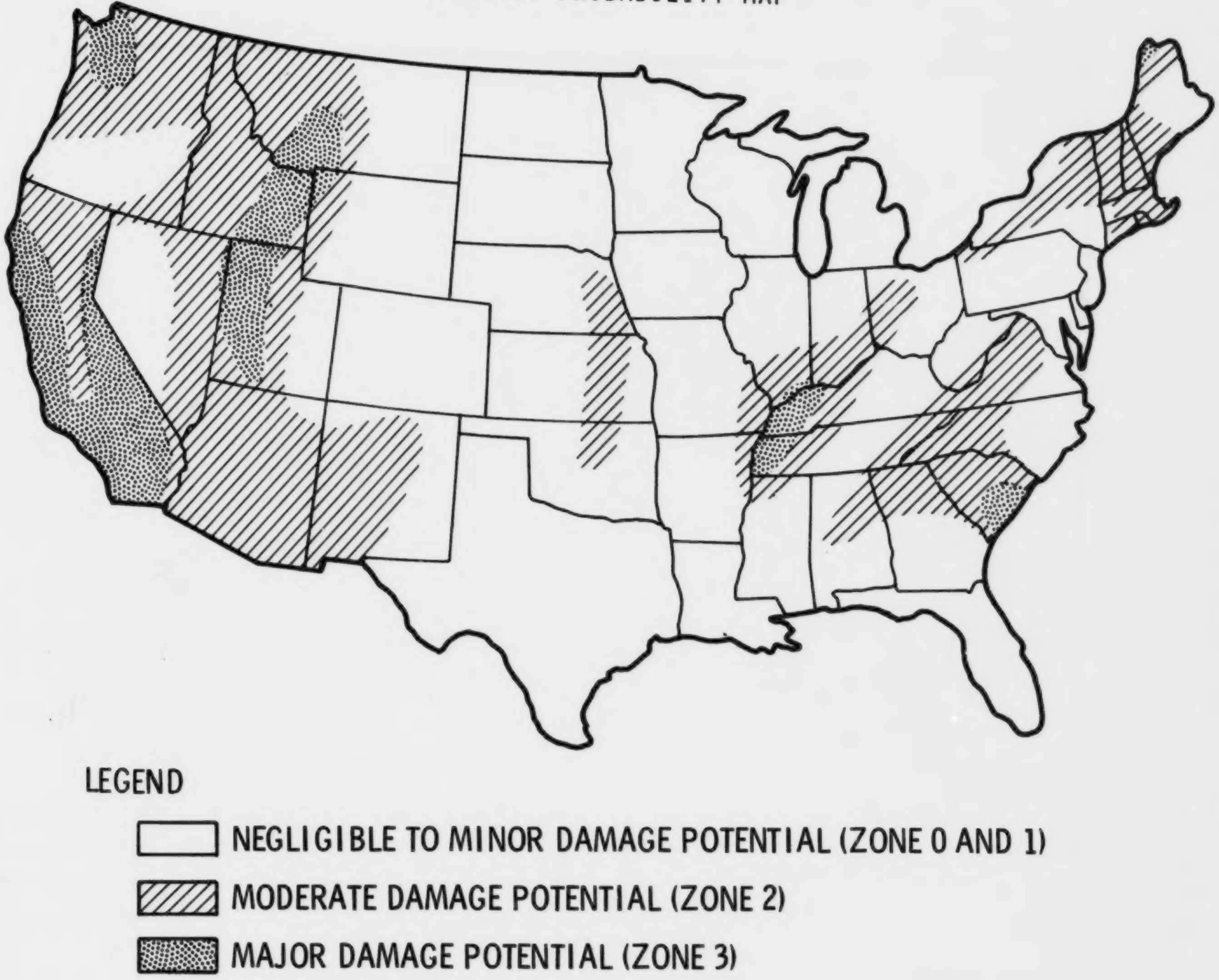
- The site should be outside floodplains or shorelands.
- The infiltration rate of surface and foundation unconsolidated materials should be very low to provide time for corrective measures to prevent leakage into any subcropping bedrock or alluvial aquifer beneath the site.
- The site should be a minimum of 2000 feet from existing wells that draw water for human or livestock consumption from an underlying aquifer.
- The site should be a minimum of five miles from municipal wells, watershed boundaries, or water intakes in static water bodies, or one mile upstream from any river intake, whether municipal or otherwise.
- The site should not be located within one mile of any active fault.
- The primary storage site should be located in a Seismic Risk Zone 0, 1 or 2 in order of preference. No primary storage site should be located in Risk Zone 3.* (See Figure 36).
- The site should be located in areas with low surface slope away from the site to obtain good drainage and to minimize landslide potential.
- The site should be located in the optimum wind direction with respect to nearby population centers, as determined by the local wind rose.
- Adequate water and power supplies should be readily available.
- The site area should have low rainfall and high evaporation.
- Either the site should be located outside the paths of recurring hurricanes and tornados or proper engineering safeguards should be developed.
- The site should not be located within, or immediately adjacent to, important recreational areas, natural/cultural areas, wilderness areas, national parks, Indian lands, wildlife refuges, or wild and scenic river areas.

---

*Seismic Risk zones have been defined by S. T. Algermissen in "Seismic Risk Studies in the United States," Fourth World Conference on Earthquake Engineering, Santiago, Chile, 1969, and are a part of the Uniform Building Code.

FIGURE 36

SEISMIC PROBABILITY MAP


LEGEND
☐ NEGLIGIBLE TO MINOR DAMAGE POTENTIAL (ZONE 0 AND 1)
▨ MODERATE DAMAGE POTENTIAL (ZONE 2)
▩ MAJOR DAMAGE POTENTIAL (ZONE 3)

- The site should be within a relatively short distance of existing rail and highway access.
- Major waste generation sources should be nearby, and wastes transported to the site should not require transfer during shipment.
- The plant should be located in an area of low species diversity and uniqueness (flora and fauna), where plant operations will have a low potential for damaging adjacent ecosystems.

The potential trade-offs among these characteristics are obvious in some cases; for example, engineered safeguard features can be included in the plant design to overcome a number of undesirable site features, particularly those in the earth sciences category. Such extra safeguards are sometimes quite costly and would need to be evaluated on a site-specific basis.

Another site-specific consideration that will require evaluation is the suitability of a location for storing or disposing of both hazardous wastes and detoxified waste salts on-site. Various areas of the country have different potential for disposing of wastes by deep-well injection, land burial or landfill. Although this potential is recognized, the many unknowns in local geologic and hydrologic conditions, with few exceptions, require that a site reconnaissance study be carried out to prove the integrity of on-site disposal/storage. Rarely is adequate detail known about potential well-injection sites to make this a viable consideration in determining site suitability at the investigative stage employed in this study. All other factors being equal, a location with a high on-site disposal potential would rank higher than one without this option. Again, this is a trade-off that requires evaluation on a site-specific basis.

Existing and Potential Hazardous Waste Sites

Table A-92 (Appendix M) is a listing of existing hazardous waste disposal/storage sites. These are primarily sites for radioactive and Department of Defense wastes, and were located conveniently near major waste generation sources (e.g., munitions plants and depots, nuclear fuel fabrication and reprocessing facilities). However, their locations also reflect isolation and many other desirable features discussed earlier. Information on non-Federal facilities is sparse, although a number of States have compiled site descriptions (See Table A-92) and regulations for State-licensed disposal facilities.

Several Federal agencies were requested to evaluate their land holdings and to provide a listing of tracts which appear to satisfy the siting criteria and could probably be made available for hazardous waste treatment or disposal operations. The resulting listing (Table A-92) identifies various tracts, most of which are located in the Western United States, with only a few convenient to the major waste generation centers in the East. Small areas on large military camps and bases (some abandoned or partly abandoned) distributed about the country would probably fulfill many of the desirable site characteristics.

Site Monitoring Requirements

One phase of this study was to determine the general site monitoring requirements, principally from the viewpoint of routine effluent releases and accidental (possibly undetected) releases and spills. It is recognized that when a site is selected a study will have to be undertaken to determine the specific monitoring needs based on site and surrounding conditions and to define sampling locations, frequencies, and analyses. However, the following considerations apply to essentially all sites.

Prior to construction a thorough ecological monitoring of the actual site and environs should be performed. The parameters to be measured would be essentially those developed for the final site selection process. Aquatic parameters would be used when water bodies are located near enough to the site to be influenced by the construction activities. Preconstruction measurements will provide the baseline to which later measurements can be compared. They will also provide the architect-engineer with recommendations concerning habitats to avoid and erosion control procedures that might be necessary. During construction, ecological monitoring would consist of periodic inspections of the site and surrounding areas to determine whether the construction recommendations are being followed and to locate any problems that develop.

Periodic monitoring (annual or biennial) of the area near the site involving the same parameters used in the preconstruction monitoring program should be conducted throughout the life of the plant to identify any alterations which might take place in the ecological environment. While normal operation of the plant is not expected to cause any adverse effects on the local ecology, periodic checks will insure that any unexpected changes are detected. These checks will also provide the necessary baseline for determining the amount of ecological damage resulting from an accident at the plant and will indicate the best procedure for restoring the natural environment following such damage.

The meteorological monitoring requirements for any processing (or disposal) plant would have two purposes--evaluation of the impact of routine trace releases of hazardous materials and use in accident release situations. With present methods of estimating atmospheric diffusion, it is recommended that a minimum of two levels of air temperature and one level of wind speed and direction be collected. Additional meteorological monitoring would be largely site dependent. Relative humidity would be required if an evaporative system is utilized, or if natural fogging occurs frequently. In addition, precipitation records should be kept for assessing the extent of leaching or scavenging by rainfall in the case of an accidental atmospheric release or spill. Air quality samplers for specific chemicals released in gaseous effluents (e.g., particulates, SO_2, NO_x) should be installed at appropriate locations based on site diffusion data.

Hydrological monitoring is required for both waste processing plants and disposal sites to detect routine and accidental releases of liquid effluents. A system of piezometers (observation wells) should be installed in unconfined aquifers around the site and concentrated in potential water and waste movement paths downgradient from the facility. Measurements of the water levels in these observation wells on a monthly basis will normally be adequate to assess the seasonal and long-term changes in groundwater contours required for predicting paths of movement should wastes enter the system. Any confined (artesian) aquifers should be similarly monitored to determine potential interconnections of aquifers and paths of waste migration. Unless there is evidence or indication of significant waste infiltration into the soils, a monthly sampling frequency should also be adequate.

Analyses should be performed on the water samples to detect detoxified salts or hazardous materials of concern. Comparison of analytical results from downgradient wells with those from upgradient wells will also provide a basis for evaluating the significance of any observed changes in water quality. A bimonthly sampling frequency should be established to assess quality changes. If there is an indication of significant waste release, the sampling frequency should be increased.

Downstream monitoring stations and a bimonthly sampling frequency should be established for surface streams in the vicinity of the waste facility to detect any water quality changes that might be due to facility operations.

Waste disposal operations such as deep-well injection pose site-specific hydrological monitoring requirements. Generally, a comprehensive pre-disposal well drilling program is required to characterize the waste injection zone, both geologically and hydrologically, and those zones above and below the waste receiving layer to determine locations and degree of interconnection. Many of these same wells may serve as monitoring structures after injection operations commence. Usually, the injection and other wells are equipped with pressure gages to provide information on injection abnormalities.

Landfill or land burial sites should be equipped with appropriate soil-settlement gages to detect short- and long-term changes in compaction/settlement rates that might indicate a breach of the storage facility's integrity. Monitoring for seismic events should not be necessary at these facilities.

EVALUATION AND EXTENSION OF THE RATING SYSTEM

Consideration was given to possible extension and modification of the site rating system used, and particularly to how it might be adapted to achieve a national (rather than regional) rating of sites. With the present system no candidate sites are omitted from the screening procedure. An apparent disadvantage of the regional system is the relative nature of the rankings. The counties within the regional boundaries were compared to determine their suitability as sites. However, comparison among counties in different regions was not made. Thus, a county ranking high in one region might rank somewhat lower if included in an adjacent region. Should the regional boundaries be significantly redrawn to meet any future needs, the existing regional ratings would need reevaluation.

A national rating system which ignores regional boundaries is appealing but is probably premature at this stage. Such a system would presumably yield a priority order of site development which would require additional information unavailable in this study. Some criterion areas (e.g. ecology) would be adaptable to rankings on a national scale, but other areas, particularly transportation, would be difficult since these evaluations depend heavily upon waste source and quantity data. A sliding value-function scale and possibly a varying weighting scale would probably be required to appropriately consider these criteria. Any change in weighting would alter the present regional ratings and possibly require that they be reevaluated. Appraisal on a regional basis results in less margin for error in the transportation category, since the site must be within one day's travel time of waste sources. The risk evaluation, which is difficult to assess because of a scarcity of data (e.g., type and severity of accidents due to material transfer, car switching, day versus night transport), would probably be the major problem of concern, since transportation economics are relatively well-defined.

The most logical approach to achieving a national rating appears to be one of determining where the county criteria rankings of 1 to 5 on the regional scale would fit into a scale of about 1 to 15 for the national appraisal. This relative value would vary for each region. For example, the vegetation type (part of the ecology criteria) in the Southwest differs significantly from that in the Northeast; thus, the highest ranked site ecologically in the Southwest may rank much higher on a national basis than the highest ranked site in the Northeast. This procedure would be followed in all four criterion areas, and the weighted rankings summed to obtain a national rating of all counties.

In summary, the procedure for developing a national rating of counties is fairly straightforward and should yield results as reliable as those of the regional ratings. However, this logical next step should be undertaken only after additional and more accurate waste generation source and quantity data are available.

SITING CONSIDERATIONS AS RELATED TO DISPOSAL METHODS

Chapter IV describes three methods for disposal/storage of the hazardous materials and of the salt solutions (brines) that result from waste processing. All of these methods require assessments of site suitability, principally with respect to the earth sciences criteria. Brine disposal in marine waters leans heavily upon evaluation of hydraulic mixing and the potential effects on marine ecosystems.

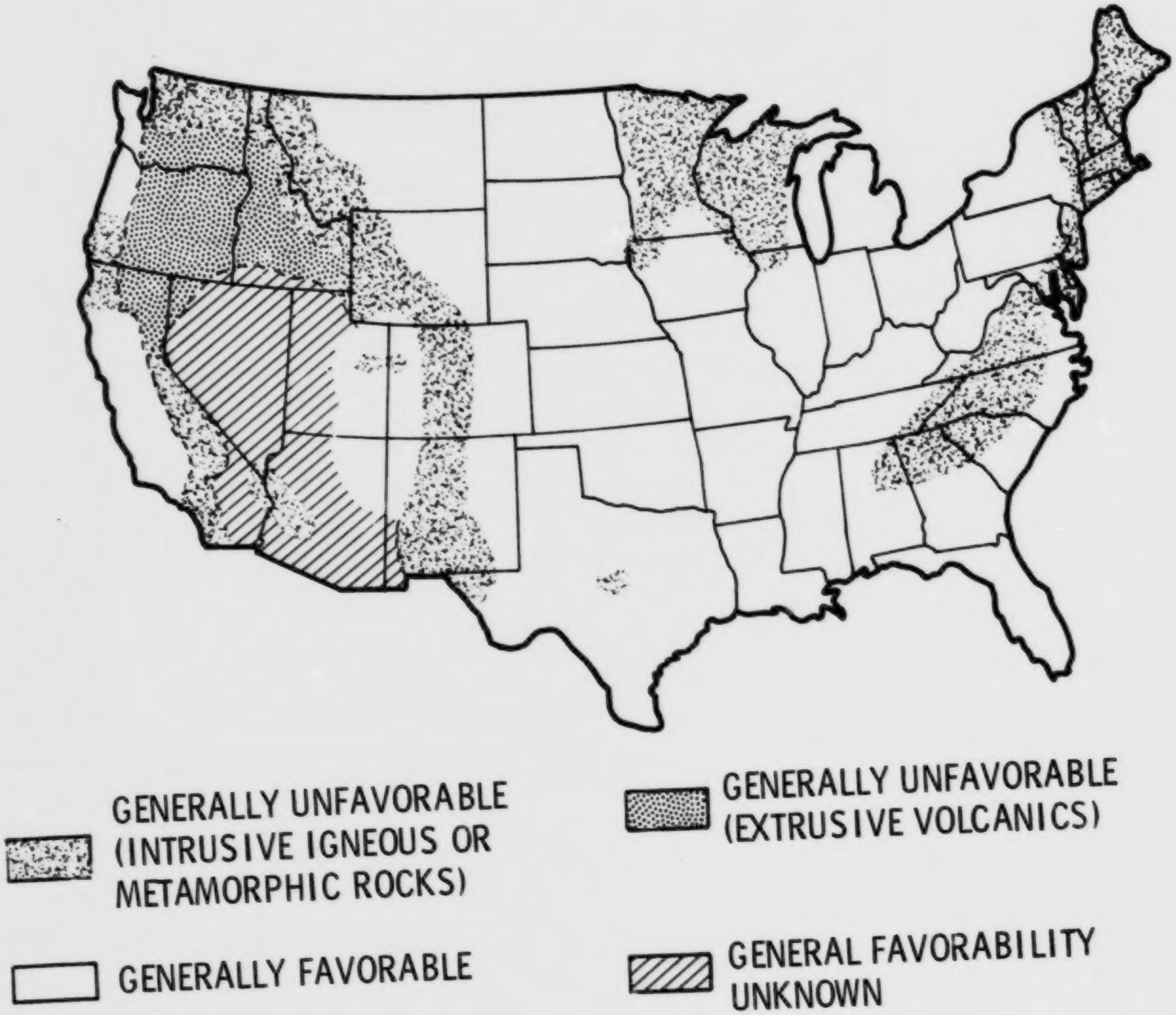
Deep-Well Injection of Brines[379-381]

The specific location of a waste injection well must be evaluated by a detailed geological subsurface investigation. However, regional geological conditions can be used to evaluate the general suitability of certain areas for injection wells.

The regional favorability map (Figure 37) indicates that certain areas of the continental United States, such as the Rocky Mountains, are generally unsuitable for waste injection wells because igneous or metamorphic rocks lie at or near the ground surface. Such rocks do not generally have sufficiently high porosity or permeability to warrant their use as a disposal formation. Areas with extensive extrusive volcanic sequences exposed are generally not suitable for waste disposal wells. Even though these rocks have porous zones, they usually contain fresh water. The waste disposal potentials of the Basin and Range Provinces (see angled lines on map) are largely unknown due to complex geologic conditions.

FIGURE 37

DEEP WELL DISPOSAL SITES


GENERALLY UNFAVORABLE (INTRUSIVE IGNEOUS OR METAMORPHIC ROCKS)
GENERALLY UNFAVORABLE (EXTRUSIVE VOLCANICS)
GENERALLY FAVORABLE
GENERAL FAVORABILITY UNKNOWN

Although the central valley of California is geologically well suited for the installation of disposal wells, several factors discourage their use. Thick sequences of sandstone in the region provide suitable injection horizons, but discontinuities in pervious strata and earthquake hazards are negative factors. Although the geology of the West Coast is complex, coastal areas north of Los Angeles may contain satisfactory potential sites for injection wells.

The Atlantic and Gulf coastal plains are underlain by thick sequences of sedimentary rock which, except in oil and gas producing areas, are generally suitable for deep well injection. The midcontinent and much of the Midwest are underlain by rather thick sequences of sedimentary rocks. Most of the injection wells in use today are located in these areas.

The final appraisal of a disposal well site is usually determined by a two-phased geologic investigation. The first phase includes an evaluation of potential sites on the basis of available data. The second phase consists of a more detailed evaluation of subsurface conditions based on information obtained from drilling a pilot hole or the injection well.

Information sought during the first phase of the investigation and prior to the installation of an injection well includes the extent, thickness, depth, porosity, permeability, temperature, water quality, and piezometric pressure of potential injection zones. The presence of impermeable confining beds, lateral changes in rock properties, the existence of faults or joints, and the occurrence of any mineral resource in the area must also be evaluated. Existing wells in the area which may penetrate the potential injection zones must be located since if not properly plugged liquid wastes could escape through these wells.

The second phase of the investigation is conducted during the drilling and testing of the injection well. Often the actual injection zone is not selected until the well has been drilled and a number of potential zones have been tested for porosity, permeability, temperature, and piezometric pressure, and until the chemical quality of water in the potential injection zones has been evaluated. Pumping tests are used to measure the permeability and water samples are obtained for chemical analysis. Other important rock properties are measured by geophysical logging, drill-stem testing tools, or by laboratory tests on core samples. The results of these geologic investigations are used not only in evaluating the feasibility of subsurface waste disposal but also to provide basic data for designing the injection well and the optimum rate of injection.

Wastes may have different requirements relating to their extent of horizontal and vertical travel with time. For example, a chemically stable dilute waste may require only injection into, and dispersion in, a body of rapidly circulating groundwater that is recharged continually. However, a biochemically unstable effluent may require a residence time within the injection zone to permit further reaction. As an example, a very concentrated waste may require a long residence time without dispersion. The following system of zone classification has been proposed.

Zone of Rapid Circulation

The zone of rapid circulation extends from the land surface downward some tens or few hundreds of feet. Injection into this zone is normally precluded.

Zone of Delayed Circulation

This zone is generally composed of fresh water which circulates continually and freely, but is retarded sufficiently that residence time varies from several to many decades or even a few centuries. Certain innocuous waste waters have been injected into this zone successfully with suitable monitoring.

Subzone of Lethargic Flow

In this subzone the native liquid is commonly saline and has very low movement measured in hundreds or even thousands of years. This subzone of lethargic flow is a primary zone for potential storage of the more concentrated wastes.

Stagnant Subzones

These subzones are, with few exceptions, several thousand feet below land surface and the fluid is hydrodynamically trapped. This zone would seem ideal for injection of very toxic wastes. However, the capability to accept and retain injected fluids needs to be assessed with extreme caution.

Dry Subzones

A common type of dry subzone would be a salt bed or dome in which free water is virtually nonexistent and which may be impermeable in a finite sense. Waste injected into such a zone would be wholly isolated from natural hydrodynamic circulation. However, since movement could occur through hydrofractures, performance of a dry subzone under injection should be assessed cautiously.

In the past, not enough attention has been given to the monitoring of deep well disposal systems. Monitoring of injection wells is desirable to determine the extent of travel of injected waste, possible well casing or cement failures, the escape of waste through fractured or faulted cap rocks or through other abandoned or operating wells, and any loss of permeability in the disposal zone due to injection.

Monitoring is also required to determine the pressure needed to maintain a constant injection rate, since this increases with time. An increase in pressure could result in decreased permeability in the vicinity of the well bore by plugging the formation. A sudden increase in the intake rate of the injection well might indicate the opening of horizontal or vertical fractures in the injection horizon and possibly in the confining beds, or the failure of the well casing, cement, or packers. Such monitoring activities should be documented and made requirements of State and Federal laws relating to deep well disposal.

Related to monitoring requirements is the necessity for developing adequately planned methods and procedures for rapidly instituting corrective actions in the event of a system failure. It is recommended that research be conducted to establish a list of proper monitoring and implementation methods associated with deep well disposal and to develop procedures for instituting corrective actions in the event of a system failure.

In addition, complete operating records are required for denoting quantities and types of wastes injected into a particular stratum. Such records usually are required by State and Federal legislation.

The use of deep well disposal techniques should be limited at the present state-of-the-art to those waste stream constituents which have low toxicity and do not have breakdown or expected reaction products demonstrating high toxicity. This recommendation is based primarily on the apparent lack of control over wastes after injection. Without proper and adequate monitoring techniques the migration of hazardous materials from the storage area may not be detected until there is an effect on the non-storage area (groundwater contamination, etc.) when it might be too late. Furthermore, even if an unexpected migration is detected, there are currently no tested procedures to reverse the migration, allow total recovery of the materials, or seal the periphery to stop further migration.

In summary, deep well disposal methods can be utilized subject to detailed geological investigations and selection, rational selection of wastes to be disposed, and proper monitoring so that disposal can be controlled to eliminate migration.

Land Burial Disposal[382-390]

Land burial is adaptable to hazardous materials that require permanent disposal. Disposal is accomplished by either near-surface or deep burial. In near-surface burial, the material is deposited either directly into the ground, in stainless steel tanks, or in concrete lined pits beneath the ground. The standard procedure for deep burial is disposal in salt mines, hard bedrock, or shale formations by use of hydraulic fracturing, as discussed previously in deep well disposal.

In land burial, the waste is transported to the selected site where it is prepared for final burial. Transportation of the wastes to the burial site can be accomplished by any of the following: by common carriers along with shipments of ordinary wastes; by contract carriers who handle only the hazardous materials to be buried but collect wastes from various sources; or by private carriers who transport their own wastes from the point of origin to the burial site.

Either solid or liquid wastes can be received at the burial site. To reduce the mobility of the wastes before burial all liquid wastes should be converted to a solid form, which requires that special solidification equipment be located at the burial site. Heavy equipment for excavation and lifting and special monitoring instruments and stations will also be required.

At present, near-surface burial of both radioactive and chemical wastes is being conducted at several Atomic Energy Commission and commercially operated burial sites. These wastes are buried in unlined trenches approximately twenty feet deep. The trenches are filled to within two to five feet of the surface and are covered with either asphalt or vegetation to reduce infiltration of water. Radioactive wastes are stored in either liquid or solid form in steel tanks enclosed in concrete.

Pilot plant studies have been conducted for deep burial in salt formations and hard bedrock. These wastes are buried approximately 1,000 to 1,500 feet beneath the ground in unlined tunnels. After the tunnel is filled, it is backfilled with salt and sealed positively (e.g., with concrete).

Land burial operates on the principle of permanent confinement and isolation from the biosphere. The wastes can be disposed of near the surface in specially constructed trenches or pits designed to retain the wastes and prevent infiltration into the soil. They can also be buried deep beneath the ground where better isolation from the biosphere is afforded. For either method the form of the waste, type of container, and site geology are of utmost importance in determining the suitability of any land burial disposal process.

The selection of a site for the disposal of hazardous materials is dependent upon several factors, including physical characteristics of the wastes to be buried, environmental characteristics of the area, operating equipment and waste handling procedures required, and the geographic characteristics of the surrounding area.

For long-lived materials, it is imperative that the disposal site be located on State or Federally-owned land to ensure that perpetual monitoring and care can be maintained. Even though Government ownership of the site is required, on-site operation can be performed by a private concern.

In selecting the location of a disposal site, the environmental characteristics of the area are important. Of principal concern are meteorology, geology, hydrology, and seismology. If a particle of gas escapes to the outside environment, its fate is determined by the prevailing meteorological conditions. Therefore, detailed meteorological data are required. The frequency of wind direction toward any given sector determines the degree of possible risk to the population within that sector from material emitted upwind. Besides wind direction, wind speed affects the dilution rate of the material. The amount and rate of rainfall are significant factors in determining the amount of material that can be leached from the wastes.

The geology and hydrology of the area determine the degree of waste confinement. Factors influencing the movement of the waste include: types of formations in the area, such as gravel, clay, sand, and shale which have variable permeabilities and sorption capacities; depths of the various formations; and depth to the water table. For a given waste, formations of low permeability and high sorption capacities generally retard waste movement. Deep formations and a large depth to water table allow increased interaction between the sediments and the wastes.

Since water represents the main vehicle of transportation for any significant quantities of wastes from the burial site, the site should be located as far as possible from any important groundwater sources. Since the groundwater can convey the wastes to the surface streams, it is necessary to determine the possible movement of groundwater from the burial site into streams, springs, and other water sources. The points of groundwater discharge must be established and the dilution capacity of the surface streams determined.

In near-surface burial, the wastes should also be buried as far as possible from any wells or surface streams in order to maximize the retention time in the soil if leaching does occur. In this way the waste can be retained by the natural processes of absorption, filtration, and ion exchange. The trenches or pits should be covered with an impermeable material (concrete, clay, shale, or asphalt) or with vegetation to prevent infiltration of water. Coverage with vegetation is less desirable than covering with impermeable material, since some infiltration of water can occur, especially during periods of heavy rainfall.

Seismic hazards such as faults, earthquakes, and tsunamis are the major phenomena to be considered. Since there is a general lack of knowledge about earthquakes, it is necessary to make conservative estimates and evaluations of the critical seismic data. A seismic probability map of the United States (Figure 37) depicts zones of no moderate and major damage The largest zone of possible major earthquake damage lies along the West Coast of the United States.

In locating the disposal site, it is necessary to provide sufficient distance between the site and the surrounding population to minimize the danger to the general public from either normal operation or accidental releases. Federal regulations (10 CFR 100) specify that nuclear reactor plants be surrounded by zones of low population. This same regulation should also apply to disposal sites for hazardous materials. The major areas with a population density of less than 30 persons per square mile are located in the midwest, southwest, and northwest regions of the United States. In addition, location of the site should be selected to minimize the distance required to transport the hazardous materials to the site.

Near-surface burial of low-level radioactive wastes is being conducted at several AEC sites and also at six commercial burial sites. The locations and descriptions of the sites are included in Appendix M, Table A-92. In addition to radioactive wastes, some of the commercial burial sites also handle certain chemical wastes. These commercial burial sites are regulated by the AEC or by an AEC agreement with the individual States.

At each of these commercial sites, the wastes are buried in trenches approximately 20 feet deep, from 25 to 60 feet wide, and from 300 to 700 feet long. The design of the trenches at each site is fairly similar. They are planned to avoid the groundwater table and are constructed with a bottom drain and sump for water monitoring. The trenches are unlined, so the extent of leaching is dependent on the permeability of the soil. At each site liquid wastes are solidified by mixing with various additives such as concrete, which absorb and solidify the wastes. These commercial facilities also offer packaging and transportation services.

Landfill Disposal

Wastes received at a hazardous waste disposal facility or generated as the residue from other neutralization/detoxification processes can be solids, liquids, sludges, or slurries, or combinations thereof. Common landfill disposal methods for these materials include (1) mixing with soil, (2) evaporation and infiltration, and/or (3) shallow burial.

Combinations of these methods can be involved in a disposal process. For example, in the spreading of a slurry on land, the liquid content may either evaporate or infiltrate into the subsoil. Solid wastes will normally be incorporated in a landfill and buried. Liquids, slurries, and sludges might also be incorporated in a landfill; however, because of the large quantity of moisture contained in these wastes, disposal practices usually involve spreading them on land or placing them in ponds to maximize evaporation or infiltration.

Landfills operate on two principles: (1) utilization of the absorptive capacity of the soil and, perhaps, some biological degradation of the wastes by soil microorganisms; and (2) storage of wastes so that they are isolated from direct contact with man and the surface environment. Some liquid wastes are currently discharged in areas where infiltration and percolation into underlying porous sediments will have limited possibility of groundwater contamination, because of depth to water or specific retention capacity. In other cases, simple shallow burial of solid wastes in a geologically "dead" area is the method of disposal. It must be stressed that the usability of any landfill site is basically determined by the site's characteristics, and investigation of these characteristics is of utmost importance to site selection.

Basic meteorology must be a part of the selection investigations for a proposed hazardous waste disposal site. The two primary elements of this investigation are determination of the average rainfall in the area and construction (from available historical data) of a wind rose for the site.

Demographic data for the area consists of a plot of the population distribution within various radii of the site which can be compared with the direction of the prevailing winds.

The geological and groundwater conditions should be investigated through a program of field inspection and testing involving soil and rock examination and the boring of test holes. The investigation should study the depth to and occurrence of groundwater, its natural quality, and the existence of natural impervious barriers. The soil types, permeability, depth and thickness of impervious layers, extensiveness of their lateral continuity, and occurrence of dip and strike of the layers should also be determined. The investigation should indicate that either geologic and hydrologic conditions will prevent migration of hazardous material onto adjacent properties or that appropriate design features are feasible to preclude such migration.

The number of test holes required to indicate underlying geologic conditions should be related to the adequacy of detailed information from other sources. Information should be provided on underlying geology to confirm rock types and groundwater conditions (absence of groundwater and/or its occurrence and quality). Shallow zone exploration should involve drilling a minimum of three test holes on the site to a depth determined by the geologist in charge of the investigation. More test holes may be necessary, depending on the size of the property and the potential for variable geologic conditions. Drilling logs should be included in the report for any test holes or monitoring wells constructed.

The area used for any hazardous waste disposal facility should be free from potential geological hazards, such as known earthquakes, faults, and landslide zones. In areas of major subsidence, this hazard should also be evaluated. Land slippage or settlement can result in rupture of levees surrounding industrial waste ponds, exposure of buried hazardous materials, or liquids breeching or overtopping pond walls. The effect on slope or levee stability of waste liquids percolating through soils or other zones of weakness must be considered in the design of waste disposal areas.

If the method of operation relies on the infiltration of large quantities of liquids, the natural soils on the property should be relatively permeable to allow infiltration to occur. Sufficient subsurface storage capacity for the liquids should exist. Conversely, if impervious basins are desired and the native soils are not suitable for that purpose, impermeable materials may have to be imported or artificial linings installed.

Soil and rock types should also be suitable for the kind of excavation work anticipated. Excavations for the disposal facility should not create hazards of slope instability or problems of erosion. Slope degrees should be consistent with good engineering practice for the particular soil or rock type involved. Erosive soils should be protected by use of mulches, hydroseed applications, or other means.

Finally, if artificial barriers are to be installed, a report should be submitted indicating the long-term competence of such a barrier. Response to seismic activity and the possibility of shrinkage and cracking due to drying or action of the hazardous wastes should be evaluated. Pre-tests should be made on all prospective liners to determine compatibility with the material being disposed.

Ocean Disposal of Hazardous Waste Materials[391-402]

The oceans have always served as the ultimate disposal sink for all the waterborne waste material carried by the natural and man-made streams discharging at their shores and for all the atmospheric pollutants scrubbed from the air by rain. In addition, with increasing frequency in this century, hazardous waste materials have been deliberately shipped out to sea and dumped as either an expedient or an economically attractive disposal technique. These hazardous waste materials have varied widely in type, in quantity, and in frequency of disposal. Three examples of this diversity may be cited as typical.

(1) "Spent" sulfuric acid (seven to ten percent H_2SO_4 and up to thirty percent $FeSO_4$) wastes from steel pickling and titanium oxide pigment manufacture processes are shipped daily to sea in specially designed barges, at the rate of 2.7 million tons per year.

(2) The U.S. Army program for deep sea disposal of obsolete chemical munitions was terminated in 1970 with the scuttling in the Atlantic of a stripped cargo vessel laden with 418 concrete vaults which contained a total of 135,432 pounds of GB chemical warfare agent (non-persistent "nerve gas") and 32,605 pounds of explosives.

(3) Individual 55-gallon drums filled with sodium metal sludge (75 percent Na, 25 percent Ca) are pierced and dropped from the decks of merchant vessels into the Gulf of Mexico on an intermittent, unscheduled basis.

The examples cited above illustrate the three basic techniques for ocean disposal of hazardous waste materials. The first technique is bulk disposal of liquid or slurry-type wastes. The waste materials are loaded into barging equipment, generally specially designed tank barges. The barges are towed to sea and emptied while underway at off-shore distances ranging from 10 to 125 miles.

In the past, the U.S. Army and Navy have stripped obsolete or surplus World War II cargo ships and loaded the ships with obsolete munitions of all types. The "explosive waste" laden hulks were towed out to the pelagic depths beyond the Atlantic and Pacific continental shelves and scuttled in predesignated sites.

The third basic technique employed for deep sea disposal of hazardous materials is the sinking at sea of containerized hazardous/toxic wastes. The individual containers, generally 55-gallon drums, are carried as deck cargo on merchant vessels and are discharged overboard at distances from shore that, dependent upon the contents, may be well over 300 miles.

The operating principles involved in the three basic techniques employed for deep sea disposal differ in their use of the ocean. Sea water is used as a reacting, neutralizing medium and/or a diluent in the bulk disposal of industrial wastes from tank barges. By contrast, obsolete munitions detonated in the deep sea employ the ocean as a cushioning, isolating medium to protect the on-shore environment from the effects of the detonation. Similarly, disposal of concrete-encased obsolete chemical munitions and obsolete conventional ordnance items (undetonated) by burial in several thousand feet of water use the ocean as a means of isolation, to minimize or prevent both potential and actual impact upon the on-shore ecosphere.

The deep sea disposal of containerized hazardous wastes is based upon the principles cited above. Where the drums are deliberately ruptured at the surface, the ocean is used as a reactant and/or a diluent. Those drums that are weighted and sunk intact beyond the continental shelf employ the thousands of feet of water for protective isolation of the barrels and their contents.

There were 281 ocean areas designated for the disposal of wastes of all types in 1969. Of these areas, 117 were used for the disposal of hazardous wastes. The regional distribution of these locations is summarized in Table 38.

TABLE 38

MARINE DISPOSAL AREAS FOR HAZARDOUS WASTES
(By Region and Waste Type)

Waste Type	Pacific	Atlantic	Gulf	Total
Industrial waste	9*	15*	16	40
Radioactive Waste	10*	25*	2	37
Explosive and chemical munitions	19*	19*	11	49
Total	38	59	29	126
(No duplicates)				

* Areas used for two or more types of wastes.

A number of studies have been made of the environmental effects of ocean dumping of hazardous materials. Because of the unique requirement by the Galveston District of the Corps of Engineers that laboratory and field studies of the effects of the wastes be filed in support of disposal applications, the majority of these studies have been carried out in the Gulf of Mexico. Results of the various studies indicate that the toxic effects of the hazardous chemical and pesticide wastes are generally limited to short time periods and areas in immediate proximity to the discharge or dump. In general, the rate of dilution is so high that after twelve hours it is impossible to detect analytically chemical differences between "contaminated" and uncontaminated sea areas.

The toxic effects of waste acid discharged from tank barges at sea are minimal; the zooplankton from samples in the immediate discharge zone were immobilized temporarily, but recovered rapidly in unpolluted water. Chlorinated hydrocarbon wastes discharged in Gulf waters killed fish and plankton in direct contact with the undiluted waste. In contrast, there was no effect observed on marine life at the surface two to four hours after discharge. The general ocean surface and upper level effects of chlorinated hydrocarbon discharge range downward from the upper extreme noted above--fish and plankton kill--through laboratory-study detected inhibition of photosynthesis and respiration, to total absence of observable effect. The possible effects of the discharged chlorinated hydrocarbons at deeper levels and on the bottom have not been determined.

Unpierced barrels loaded with sodium sludge (75 percent metallic sodium, 24 percent metallic calcium) have on two occasions been retrieved in the Gulf of Mexico by fishermen. These barrels were not pierced prior to dumping as prescribed, nor were they dumped in the prescribed area. Pierced barrels of the sodium sludge exploded when dropped overboard, produced no significant effects on the microbiota and, due to the probable barrenness of the area, produced no visible fish kill.

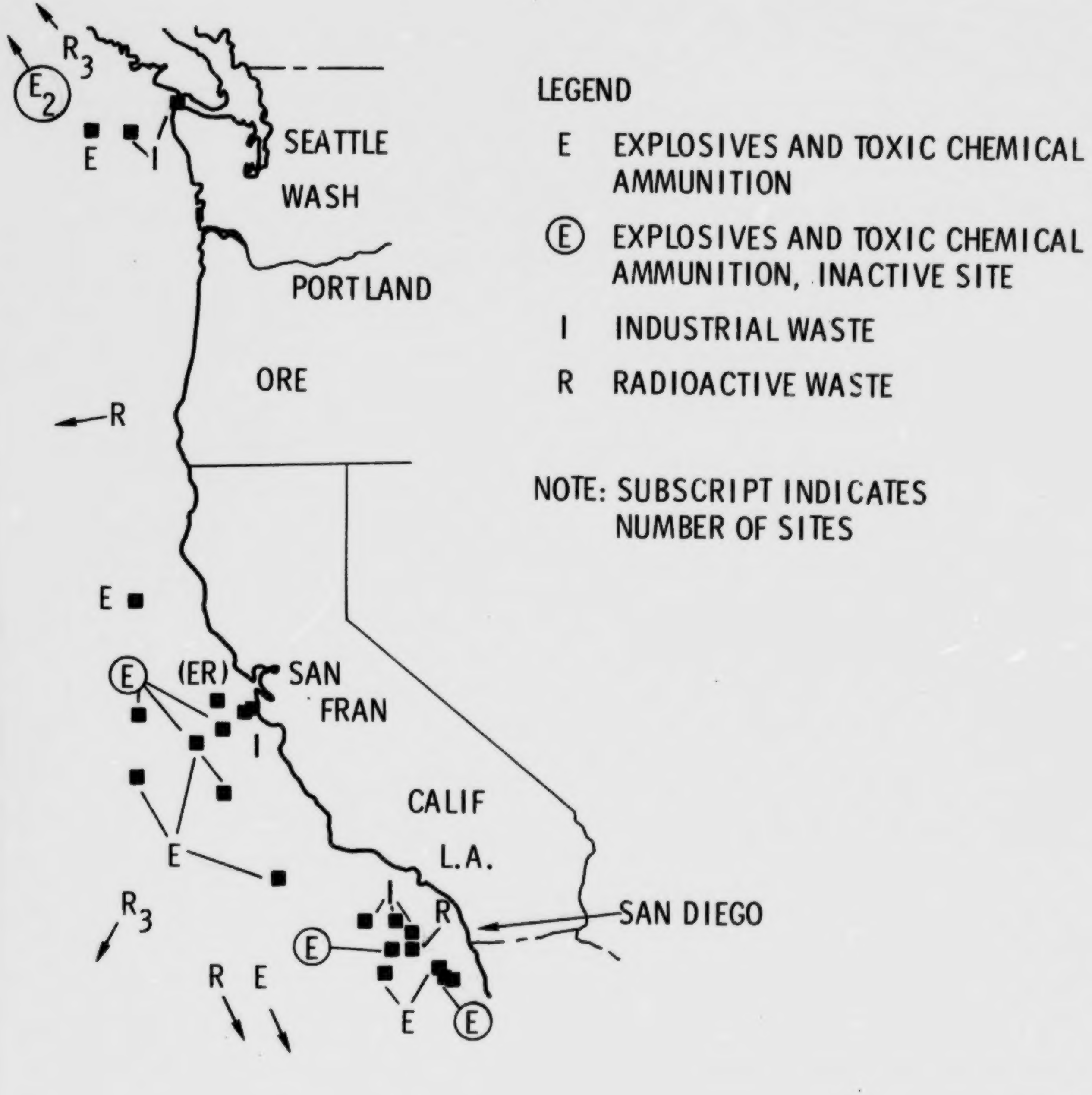
Deep sea disposal bulk transport systems vary from modern, specialized tank barges to obsolete hulks. The majority of bulk liquid and slurry hazardous wastes dumped at sea are transported in specially designed tank barges of from one to five thousand short tons in capacity. The tank barges are of double-skinned bottom construction and must be certified for ocean waters by the U.S. Coast Guard. The barge cargo is under U.S. Coast Guard regulations covering the bulk shipment of chemicals from the United States.

Industrial waste-laden barges are transported to the industrial waste disposal areas designated in Figures 38, 39, and 40 for the Pacific, Atlantic, and Gulf of Mexico Coast, at off-shore distances that depend upon the type of waste and the regulatory procedures. Typical distances are, for acid wastes, 15 miles from New York City; for toxic chemical wastes, 125 miles into the Atlantic; for Gulf of Mexico operations, 125 miles from the coast (at the 2,400 foot depth line). In the disposal area, typical barge speeds from 3 to 6 knots are used; typical discharge is at 6 to 15 feet submergence, at rates that vary between 4 and 20 tons per minute.

Containerized toxic industrial wastes, as noted earlier, are dumped at sea after transport as deck cargo on either merchant vessels or contract disposal vessels. The individual containers are either ruptured at the surface or weighted for sinking. There is no single "operating design" or operating practice that covers the wide variety of materials thus disposed of.

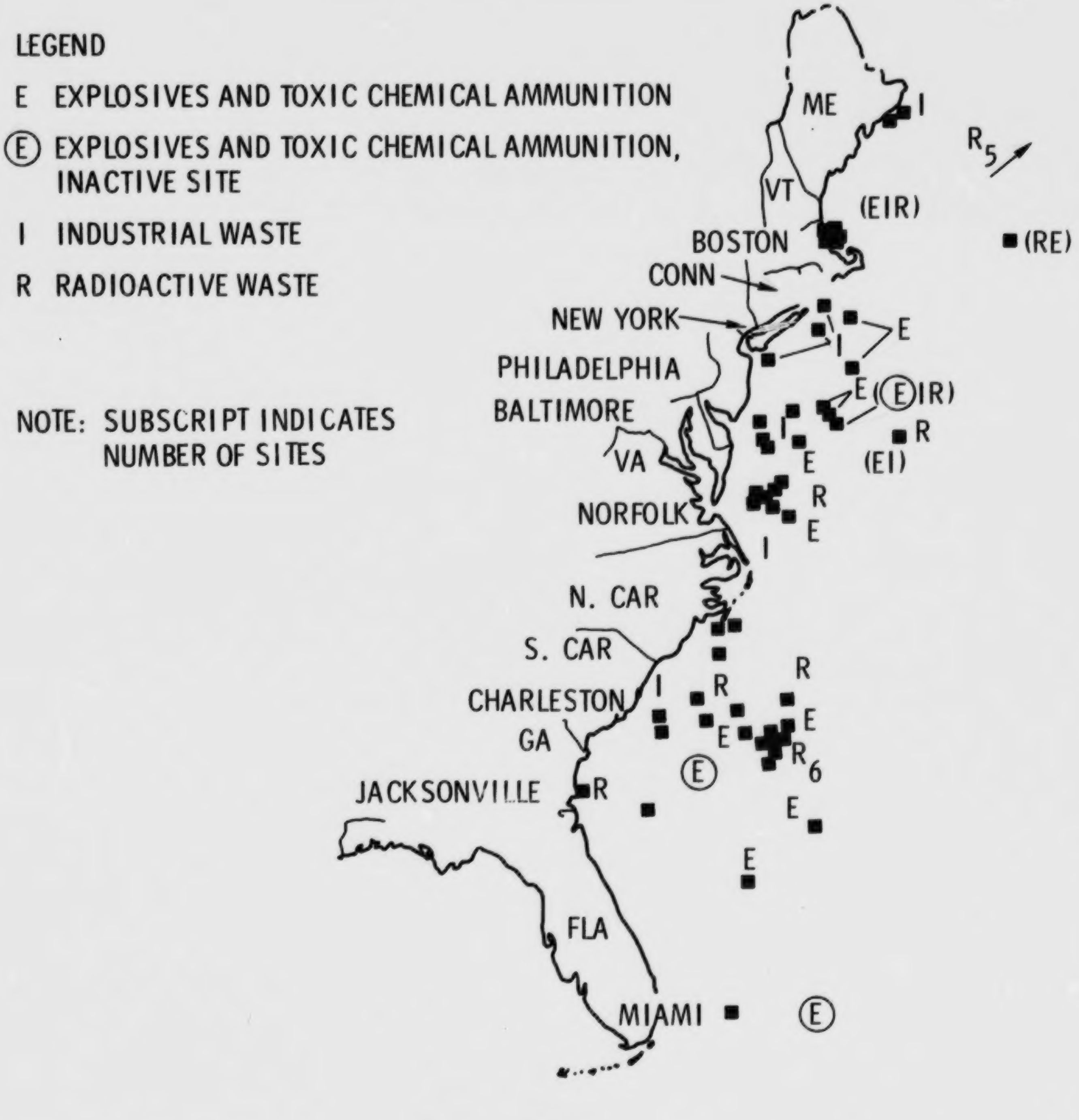
FIGURE 38

PACIFIC COAST DISPOSAL AREAS



R_3
E_2
E
I
SEATTLE
WASH
PORTLAND
ORE
R
E
E
(ER)
SAN FRAN
I
CALIF
E
L.A.
R_3
I
R
SAN DIEGO
E
R
E
E
E
LEGEND
E EXPLOSIVES AND TOXIC CHEMICAL AMMUNITION
Ⓔ EXPLOSIVES AND TOXIC CHEMICAL AMMUNITION, INACTIVE SITE
I INDUSTRIAL WASTE
R RADIOACTIVE WASTE
NOTE: SUBSCRIPT INDICATES NUMBER OF SITES

FIGURE 39
ATLANTIC COAST DISPOSAL AREAS


LEGEND

E EXPLOSIVES AND TOXIC CHEMICAL AMMUNITION

Ⓔ EXPLOSIVES AND TOXIC CHEMICAL AMMUNITION, INACTIVE SITE

I INDUSTRIAL WASTE

R RADIOACTIVE WASTE

NOTE: SUBSCRIPT INDICATES NUMBER OF SITES

ME
I
R_5
VT
(EIR)
BOSTON
(RE)
CONN
NEW YORK
E
I
PHILADELPHIA
E
(Ⓔ IR)
BALTIMORE
I
R
VA
E
(EI)
R
NORFOLK
E
I
N. CAR
S. CAR
R
I
R
CHARLESTON
E
GA
E
R_6
Ⓔ
JACKSONVILLE
R
E
E
FLA
MIAMI
Ⓔ

FIGURE 40

GULF OF MEXICO DISPOSAL AREAS

LEGEND

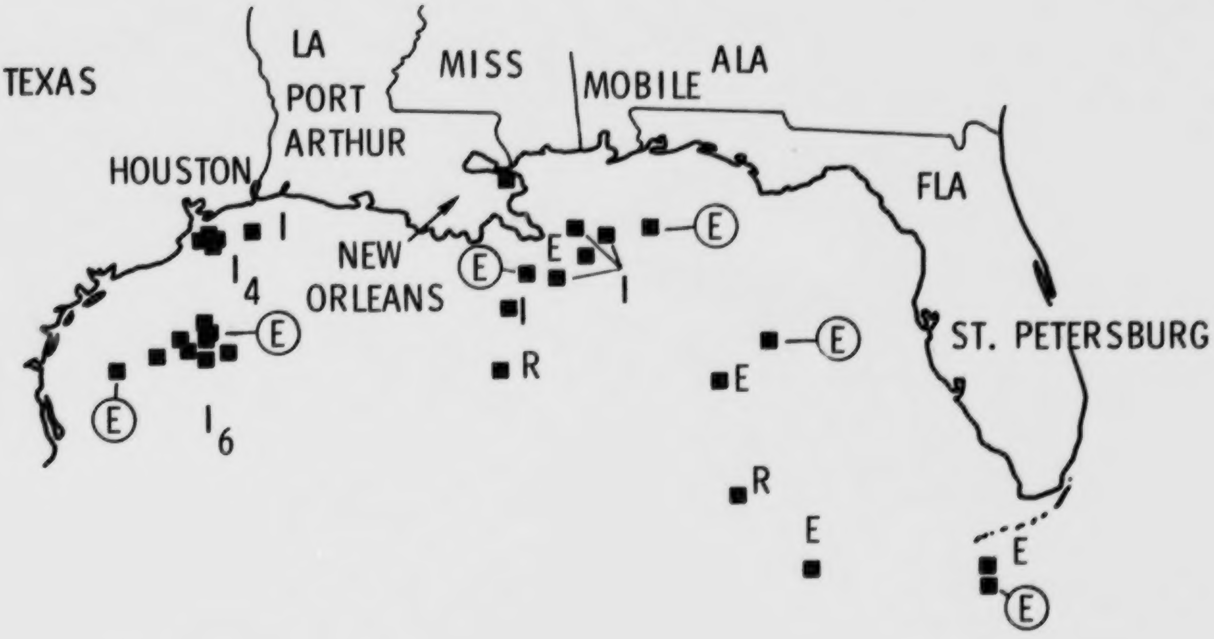
E EXPLOSIVES AND TOXIC CHEMICAL AMMUNITION

Ⓔ EXPLOSIVES AND TOXIC CHEMICAL AMMUNITION, INACTIVE SITE

I INDUSTRIAL WASTE

R RADIOACTIVE WASTE

NOTE: SUBSCRIPT INDICATES NUMBER OF SITES


TEXAS
LA
PORT ARTHUR
MISS
MOBILE
ALA
HOUSTON
FLA
I
I_4
NEW ORLEANS
Ⓔ
E
I
I
Ⓔ
Ⓔ
R
I_6
Ⓔ
E
ST. PETERSBURG
R
E
E
Ⓔ

Conclusions

The selection and ranking of hazardous waste processing and disposal sites on a nationwide basis presents a challenge of no small magnitude. The initial approach of establishing criteria, with their ranking values and weightings, appears to be sound and corresponds to similar methods used by industry in site selection. Problems arise from the absence of reliable data on the performance of existing facilities, since only several exist that even remotely approach the designs described in Chapter IV.

Waste generation data also complicate the integration of transportation risk and economic parameters into the site suitability assessment. The study team believes that transportation considerations will weigh heavily in determining the service area of a waste treatment plant. Accordingly, the regional approach to site selection reflects transport distances that appear reasonable at this time in light of the available data.

As discussed earlier in this chapter, attention must be given to ways in which a high-ranked area (county) outside but near the periphery of a region can be integrated into both its own region and the adjacent region--interregional interactions. Further, the conversion of the rating system to achieve nationwide (versus regional) ratings of the counties presents an additional challenge, one which will be crucial with respect to transportation criteria.

The selection of county size as the controlling ranking criterion appears near optimum with respect to a manageable evaluation matrix, and to uniformity and validity of available information. Certainly, any significantly larger area would require data smoothing and integration which might compromise the assessment accuracy, reduce the desirable spread in the final ratings, and eliminate the low- and high-ranked sites. Choosing an area smaller than the county would present nearly insurmountable problems with respect to the size of the evaluation matrix and to adequate, uniform data across the country. Too many potential sites could be overlooked in the screening process.

No attempt was made at this stage of site evaluation to relate suitability to any logical order of site development. Such determinations must await the improved waste generation data and associated economic information that will logically come from implementation of a hazardous waste regulatory program.

The rating output of counties (Table A-93, Appendix M) is, therefore, not a firm and final listing in any sense. Rather, it should be considered as a guide to further more detailed evaluations and a starting point for those who might become involved in reconnaissance studies for detailed site selection.

CHAPTER CONTENTS

CHAPTER VII

IMPLEMENTATION

	Page No.
BRIEF	309
INSTITUTIONAL ALTERNATIVES	311
DISCUSSION OF ALTERNATIVES	312
Alternative One: No Change in Existing System	312
Advantages	312
Disadvantages	312
Degree of Federal Involvement	312
Implementation Strategy	312
Summary	312
Alternative Two: State Responsibility and Standards	313
Advantages	313
Disadvantages	313
Degree of Federal Involvement	313
Implementation Strategy	313
Summary	314
Alternative Three: State Responsibility and Standards with Federal Subsidy to Finance State or Locally Operated Systems	314
Summary	314
Alternative Four: State Responsibility and Standards with Federal Tax Incentives to Encourage Satisfactory Hazardous Wastes Management	314
Advantages	314
Disadvantages	314
Degree of Federal Involvement	315
Implementation Strategy	315
Summary	315

CHAPTER CONTENTS (Continued)

Page No.

Alternative Five: State Responsibility with Standards Meeting Federal Guidelines 315

- Advantages 316
- Disadvantages 316
- Degree of Federal Involvement 316
- Implementation Strategy 316
- Summary 316

Alternative Six: State Responsibility and Standards Meeting Federal Guidelines with Federal Subsidy to Finance State or Locally Operated Systems 317

- Advantages 317
- Disadvantages 317
- Degree of Federal Involvement 317
- Implementation Strategy 317
- Summary 318

Alternative Seven: Federal Responsibility and Standards with No Management System 318

- Advantages 318
- Disadvantages 318
- Degree of Federal Involvement 318
- Implementation Strategy 318
- Summary 318

Alternative Eight: Federal Responsibility and Standards with Federal Subsidy to Finance State or Locally Operated Systems 319

- Advantage 319
- Disadvantages 319
- Degree of Federal Involvement 319
- Implementation Strategy 319
- Summary 320

Alternative Nine: Federal Responsibility and Standards with No Management System but with Federal Tax Incentives to Encourage Satisfactory Waste Management 320

CHAPTER CONTENTS (Continued)

Page No.

Advantages 320
Disadvantages 320
Degree of Federal Involvement 320
Implementation Strategy 321
Summary 321

Alternative Ten: Federal Responsibility and Standards with Private Facility Ownership Operating Under State Licensing and Enforcement 321

Advantages 321
Disadvantages 321
Degree of Federal Involvement 322
Implementation Strategy 322
Summary 322

Alternative Eleven: Federal Responsibility, Standards, and Facility Ownership, with Operation by Private Enterprise Under Federal Contract 322

Advantages 322
Disadvantages 322
Degree of Federal Involvement 323
Implementation Strategy 323
Summary 323

Alternative Twelve: Federal Responsibility, Facility Ownership, and Operation 323

Advantages 323
Disadvantages 324
Degree of Federal Involvement 324
Implementation Strategy 324
Summary 324

Institutional Alternatives Matrix 324

Summary and Conclusions 327

LEGISLATIVE REVIEW - STATE LEGISLATION/REGULATIONS 327

FEDERAL LEGISLATION/REGULATIONS 329

CHAPTER CONTENTS (Continued)

	Page No.
Substantive Aspects	*332*
Water	*333*
Air	*335*
Pesticides	*335*
Toxic Substances	*336*
Land Use	*337*
Environmental Impact	*338*
Legislative References	*339*
Recent Legislation	*340*
Transportation Aspects	*341*
Administrative Structure	*341*
Regulations	*344*
Interested Agencies: Jurisdiction	*345*
Inspection of Containers Before Transit	*346*
Inadequacies of the Present Federal System of Controlling Transportation of Hazardous Wastes in Interstate Commerce	*346*
Lack of Resources	*347*
Lack of Coordination Between DOT and Other Agencies	*347*
Inadequacies in Substance of Present Standards	*348*
Lack of Uniform Investigatory Processes	*348*
Lack of Information to the States and Municipalities	*349*
Lack of Information to Industry	*350*
Enforcement Problems	*350*
SUMMARY	*350*
Policy-Making	*350*
Lack of Resources	*351*
Coordination	*351*
Substantive	*351*
FINANCING CONSIDERATIONS	*352*

CHAPTER VII

IMPLEMENTATION

BRIEF

As pointed out in Chapter I, a system for the management of hazardous wastes will consist of both physical entities (transportation systems, processing facilities, and disposal sites) and the institutional and financial arrangements necessary to the functioning of the system. In addition, a number of other issues are involved in successful implementation:

- the range of implementation options;
- effectiveness in meeting the goal;
- Federal cost and employment;
- legislative requirements;
- compatibility with other efforts in public health and environmental protection; and
- private sector involvement and equity.

The first of these is a key issue. There are numerous separate and distinctly different potential implementation mechanisms, ranging from a highly restrictive Federally owned and operated system to the simple, unrestricted publication of guidelines. The optimum mechanism obviously lies within this spectrum.

From this wide selection of possible implementation methods a comparative analysis of several viable alternatives has been made. And, since institutional arrangements are founded principally upon laws, related State and Federal legislation was examined. As a result of this analysis, advantages and disadvantages of 12 alternative institutional arrangements and the strategy required for the implementation of each have been identified.

A matrix (given on page 325) summarizes each institutional alternative and rates (on an ascending scale, with the least desirable rating as the highest number) its six essential characteristics. The total rating, as well as the individual values for each alternative, could be useful in selecting the optimal institutional arrangement to effectively handle the nation's hazardous wastes. Finally, the institutional arrangement considered most suitable for managing hazardous wastes in the United States is discussed.

Note that considerations given in this chapter refer only to nonradioactive hazardous wastes. Radioactive wastes have traditionally been the subject of Federal controls and, in the case of high level wastes, Federal stewardship in final disposal. A more complete discussion of the special attributes associated with radioactive wastes is given in Chapter V.

Certain key findings and conclusions regarding implementation schemes have become apparent in the course of these efforts:

- Taking all things into consideration--the magnitude of the problems to be solved, the cost to society and its equitable distribution, incentives for diminution of the problem, and general administrative workability--the most effective institutional alternative appears to be a combination of Federal responsibilities and standards for hazardous waste management with the operation of privately owned waste processing, storage, and disposal facilities under licenses issued and controlled by the State governments.

- New regulations and controls in hazardous waste management can be expected to result in minor restructuring of business practices if the arrangement described above is adopted. The largest impact will be the accelerated development of an industry devoted to providing hazardous waste management services which now exists in only a rudimentary form.

- The timing and emergence of a well-developed hazardous waste management service for industry will be sensitive to the nature of the regulations promulgated, and particularly to their level of enforcement. In essence, regulatory and enforcement programs can create a market for such a service industry.

- Legislative activities in hazardous wastes management at State and lower jurisdictional levels are at present minimal. This perhaps indicates that short-term, more visible problems attract the most attention and long-term consequences are not yet fully appreciated.

INSTITUTIONAL ALTERNATIVES

The following twelve institutional options were selected from the many possible to cover a range of responsibility and standards, incentives, and Federal investment.

1. No Change in Existing System
2. State Responsibility and Standards
3. State Responsibility and Standards with Federal Subsidy to Finance State or Locally Operated Systems
4. State Responsibility and Standards with Federal Tax Incentive to Encourage Satisfactory Hazardous Waste Management
5. State Responsibility and Standards Meeting Federal Guidelines
6. State Responsibility and Standards Meeting Federal Guidelines with Federal Subsidy to Finance State or Locally Operated Systems
7. Federal Responsibility and Standards, but No Management System
8. Federal Responsibility and Standards with Federal Subsidies to Finance State or Locally Operated Systems
9. Federal Responsibility and Standards, but Private Management System with Federal Tax Incentives to Encourage Satisfactory Waste Management
10. Federal Responsibility and Standards with Private Facility Ownership Operating Under State License and Regulation
11. Federal Responsibility and Facility Ownership, Operated by Contract to Private Enterprise
12. Federal Responsibility, Facility Ownership, and Operation

DISCUSSION OF ALTERNATIVES

Alternative One: No Change in Existing System

This alternative is simply a continuation of the status quo under which hazardous wastes are disposed of in a variety of ways by a variety of public and private waste handlers. The alternative envisions no change in standards or regulatory requirements and no incentive or subsidy of any kind.

Advantages

1. No Federal money would be required to implement this alternative.
2. No legislative changes would be required.
3. No new Federal employees would be required.
4. This alternative is now operating--nothing further needs to be done.

Disadvantages

1. The present system is generally considered to be ineffective in protecting public and environment from adverse effects of hazardous wastes.
2. Little or no stimulus is offered to private sector involvement due to lack of effective regulation and the high risk involved in operation.

Degree of Federal Involvement

This alternative represents the minimum possible involvement of the Federal Government in the management of the nation's hazardous wastes, short of decreasing the current involvement.

Implementation Strategy

None is required since this alternative is currently in operation.

Summary

This alternative is not satisfactory and should not be considered seriously since the present method of handling hazardous wastes is inefficient and ineffective in protecting the public and the environment from their possibly adverse effects.

Alternative Two: State Responsibility and Standards

This alternative involves enactment of Federal legislation to place the responsibility for hazardous waste management with State governments and direct them to adopt appropriate State standards for this operation. It could involve Federal financial assistance (i.e., program grants) to State regulatory agencies to assist them in carrying out this alternative.

Advantages

1. Few additional Federal funds would be required to implement this alternative. Those required would consist principally of program grants to State regulatory agencies.
2. Only minor changes in existing legislation would have to be effected.
3. Very few new Federal employees would have to be hired.

Disadvantages

1. This mechanism would be ineffective in bringing about necessary changes in existing unsatisfactory waste management systems.
2. This alternative offers little, if any, incentive to private enterprise to invest capital and resources in hazardous waste management.

Degree of Federal Involvement

This alternative increases slightly the present involvement of the Federal government in traditional areas of management of the nation's hazardous wastes.

Implementation Strategy

Drafting and submission of legislation to Congress directing State governments to enact appropriate standards and enforce them would be required. The legislation would also have to authorize program grants to State regulatory agencies to assist them in enforcing the standards. These changes could be incorporated into amendments to the present Federal Solid Waste Disposal Act which expires June 30, 1974.

Summary

Although this alternative would probably result in more effective management systems, it still lacks the necessary involvement to assure proper operation.

Alternative Three: State Responsibility and Standards with Federal Subsidy to Finance State or Locally Operated Systems

This alternative contains the basic elements of Alternative Two plus the inclusion of Federal subsidies or construction grants to State or local waste management agencies for constructing and operating hazardous waste management facilities until such time as user fees would financially sustain the system.

Summary

Although more efficient than Alternatives One and Two in properly handling hazardous wastes, this alternative still lacks the desired level of effectiveness. This factor, coupled with a high Federal cost, detracts from adoption of this alternative as the preferred system.

Alternative Four: State Responsibility and Standards with Federal Tax Incentives to Encourage Satisfactory Hazardous Wastes Management

In addition to the elements of Alternative Two, this alternative contains a Federal tax incentive for industries to encourage satisfactory hazardous waste management. The incentive could allow a favorable depreciation schedule on capital investment or actually reduce corporate tax rates if satisfactory hazardous waste management were demonstrated.

Advantages

1. Cost to Federal Government would be moderate to low (there would be some loss in revenue due to the tax incentive).

2. This alternative would encourage waste producers to solve their own problems.

3. Only minor increase in Federal employment would be required to implement this alternative.

Disadvantages

1. This alternative could be difficult to administer.

2. Sources of hazardous wastes other than industry are not considered.

3. Tax incentive is minimally attractive to marginal waste producers.

4. This alternative lacks promise of effective hazardous waste management.

5. Although waste producers might be stimulated to solve their own problems, the alternative offers very little encouragement to the private waste management sector to enter the field with its capital.

Degree of Federal Involvement

The alternative represents a slight increase in Federal involvement in the management of hazardous wastes as compared with present levels of activity. The increase would be in areas traditionally considered to be within Federal purview.

Implementation Strategy

This alternative would require substantial changes in existing legislation, principally concerning the details of the tax incentive. The Treasury Department and EPA would have to work closely together to develop workable recommended legislation. Following enactment, a mechanism would be required to inform industry about eligible systems and to regularly inspect them for adequacy.

Summary

Management of this alternative appears awkward, with only minimal prospects for successfully coping with the problems of hazardous waste management.

Alternative Five: State Responsibility with Standards Meeting Federal Guidelines

This alternative contains the basic elements of Alternative Two, with the added requirement that State standards meet Federal guidelines for managing hazardous wastes. Further, if State standards do not meet Federal guidelines or if the State regulatory agencies fail to adequately enforce the standards, the Federal government could preempt the State agencies, requiring the adoption of meaningful standards and/or their enforcement.

Advantages

1. This alternative would require only minimal increase in Federal funds.
2. Implementation would require few new Federal employees.
3. This alternative offers moderate encouragement to involvement of the private sector in the management of hazardous wastes.

Disadvantages

1. The threat of Federal enforcement proceedings increases the projected effectiveness of this alternative over Alternatives One and Two, but the system lacks the mechanism to assure early satisfactory hazardous waste management.
2. The dichotomy of institutional responsibility for enforcement could cause conflict.

Degree of Federal Involvement

This alternative increases the level of Federal involvement in the management of hazardous wastes in the area of regulation, making it comparable to existing legislation in air and water pollution control.

Implementation Strategy

While significant changes in existing legislation would be required to implement this alternative, they would be relatively simple to frame because of past history in air and water pollution control. Following enactment, a major program of coordination with State regulatory agencies would have to be initiated to insure effective operation.

Summary

Low Federal cost appears to be the chief advantage of this alternative. It lacks an effective mechanism to assure satisfactory hazardous waste management and appears to have small chance for success.

Alternative Six: State Responsibility and Standards Meeting Federal Guidelines with Federal Subsidy to Finance State or Locally Operated Systems

This alternative contains the basic elements of Alternative Five with the addition of a Federal subsidy or construction grant to finance systems. Compliance with State standards and Federal guidelines would be prerequisite to receiving a grant.

Advantages

1. Construction grants provide a mechanism for initiation of a waste management system and promise a fairly effective program.
2. Funds would be provided at a relatively early date for implementing the proposed system.

Disadvantages

1. A significant increase in Federal funds would be required to implement this alternative.
2. A significant number of additional Federal employees would be required.
3. This alternative would offer no encouragement to involvement of private sector resources in the area of hazardous waste management. In fact, it might drive out those now involved.
4. Lack of availability of Federal funds supporting construction grants could stifle program's initiative.

Degree of Federal Involvement

This alternative represents a significant increase in the Federal government's involvement in management of the nation's hazardous wastes. Such increased involvement has precedence, however, in the similar Federal program in water pollution control.

Implementation Strategy

The strategy for implementing this alternative would be basically identical to that of Alternative Three, with the added difficulty of lack of support from State agencies. Similar delays would be experienced.

Summary

While this would be the most effective of the alternatives discussed so far, the high Federal cost and deterrent effect on the involvement of private enterprise would offset this advantage. Also, complete control through a national management system is lacking, and thus maximum effectiveness would still not occur despite high Federal costs.

Alternative Seven: Federal Responsibility and Standards with No Management System

This alternative would entail Federal legislation delegating responsibility for the satisfactory management of hazardous wastes to the Federal Government through promulgation and regulation of standards. Lacking, however, is any system for accomplishing these goals.

Advantages

1. A small increase in Federal funding or payroll would be required to implement this alternative.

2. Only moderate legislative change would be necessary.

Disadvantages

1. Without an effective management system, this alternative would be largely ineffective in coping with hazardous wastes problems.

Degree of Federal Involvement

This alternative represents a major increase in Federal Government involvement in the management of hazardous wastes, principally because responsibilities formerly held by State governments would fall to the Federal establishment. Similar responsibilities have already been delegated to the Federal Government in the area of handling low level radioactive material.

Implementation Strategy

New legislation, which would have to be drafted and submitted for implementation, might initiate debate on the philosophical issue of State versus Federal responsibility. Once adopted, this alternative could be implemented fairly quickly.

Summary

This alternative represents a compromise between Federal regulation and no Federal expenditure or involvement in the actual solution of the problem. While it offers promise for less than a completely satisfactory approach, it is unlikely to be a total failure.

Alternative Eight: Federal Responsibility and Standards with Federal Subsidy to Finance State or Locally Operated Systems

This alternative has the basic elements of Alternative Seven with the addition of Federal subsidies or construction grants to State or local agencies for the purpose of constructing and operating hazardous waste management facilities. Prerequisite to receiving a grant would be compliance with Federal standards.

Advantage

1. This alternative offers a reasonable prospect for an effective program due to coupling of Federal responsibility with funds to finance systems.

Disadvantages

1. This alternative would demand large increases in Federal funds and employees. High costs would continue until user fees could sustain the system.
2. Adoption of this alternative would virtually preclude involvement of private sector resources.
3. Delays in construction grant funds would seriously impair the effectiveness of this approach.

Degree of Federal Involvement

This alternative represents a major increase in Federal involvement, principally in delegating responsibility for hazardous waste management to the Federal Government and authorizing construction grants to construct and operate necessary facilities.

Implementation Strategy

This alternative would require strategy similar to that of Alternative Seven with the additional difficulty of authorizing a construction grant program and the attendant delays in implementing such a program after enactment. Time required to develop regulations and employ necessary staff might cause considerable delay in the implementation of the programs envisioned under this alternative.

Summary

This alternative offers a good chance for an effective program; however, high Federal cost would be entailed. In achieving effectiveness, involvement of the private sector would be further precluded and it would probably be forced out of the current market.

Alternative Nine: Federal Responsibility and Standards with No Management System but with Federal Tax Incentives to Encourage Satisfactory Waste Management

This alternative contains the basic elements of Alternative Eight with the substitution of a Federal tax incentive to encourage satisfactory waste management instead of a direct Federal subsidy for the construction of waste management facilities. The tax incentive could be positive or negative (i.e., a tax benefit for a job well done or a penalty if responsibilities were not being met).

Advantages

1. This alternative is slightly more effective than Alternative Seven because of the tax incentive.

2. Only moderate increases in Federal cost and number of Federal employees would be required to implement this alternative.

Disadvantages

1. Positive or negative tax incentives are of doubtful value in assuring an effective program of hazardous waste management.

2. This alternative would do nothing to encourage participation of private sector waste managers, although it might encourage private waste producers to invest capital and operational funds.

3. Complex legislation would be required, probably involving the Environmental Protection Agency and the Treasury Department.

Degree of Federal Involvement

This alternative represents a major increase in Federal Government involvement in management of the nation's hazardous wastes. In this case, the involvement is not operational but regulatory.

Implementation Strategy

This alternative would require strategy similar to that of Alternative Seven, with the additional complication of authorizing a tax incentive program. The legislation could be further complicated by the involvement of two or more government agencies, thus requiring significant coordination to implement the law after enactment.

Summary

This alternative represents minimal increase in Federal cost in return for doubtful effectiveness and no stimulation of private sector involvement. In addition, it would be administratively cumbersome.

Alternative Ten: Federal Responsibility and Standards with Private Facility Ownership Operating Under State Licensing and Enforcement

In addition to the basic elements of Alternative Seven, this alternative includes Federal operational responsibility through a specified management system. The system would require operation of facilities by private operators under Federal standards with States involved in standard enforcement. Private sector capital and operating costs would be reimbursed by user fees from industries or governmental units contributing the hazardous wastes.

Advantages

1. This alternative offers the maximum level of effectiveness through a specified national system.

2. Maximum stimulation for involvement of private sector resources would be provided.

3. Minimal increases in Federal funding and employment would be required.

4. Meaningful participation by State authorities is included.

Disadvantages

1. This alternative depends upon the participation (including financing) of the private sector for success.

2. Active State participation must be promoted.

Degree of Federal Involvement

This alternative represents the most significant Federal involvement in the management of the nation's hazardous wastes of any of the alternatives so far presented. The handling of radioactive materials by the Atomic Energy Commission serves, to a degree, as a precedent for this type of involvement.

Implementation Strategy

This alternative would require strategy as indicated for Alternative Seven with the added difficulty of setting up a mechanism for initiating and operating the system under license. Those favoring involvement of State governments might strongly oppose the legislation unless implementation of State involvement is clearly recognized as a Federal responsibility. Following enactment, delays might be encountered if private enterprise could not be attracted to this business opportunity.

Summary

This alternative offers a highly effective program with minimal Federal cost and maximum participation of private sector capital and resources.

Alternative Eleven: Federal Responsibility, Standards, and Facility Ownership, with Operation by Private Enterprise Under Federal Contract

This alternative contains the basic elements of Alternative Seven with the addition of Federal operational responsibility through a specified management system. The Federal Government would own the processing and disposal facilities which would, in turn, be operated by private enterprise under contract to the Federal Government.

Advantages

1. This alternative offers the maximum level of effectiveness through a specified national system.

2. Maximum stimulation for involvement of private sector resources would be provided.

Disadvantages

1. This alternative would have a high Federal cost until user fees made the system self-sustaining.

2. The success of this alternative would depend upon the availability of both qualified private firms to operate the systems and to appropriate funds to finance them.

3. Meaningful participation by State solid waste management agencies would be precluded.

Degree of Federal Involvement

This alternative represents an even greater Federal involvement in management of the nation's hazardous wastes than that of Alternative Ten.

Implementation Strategy

Strategy similar to that of Alternative Seven and Ten would be required, with the added difficulty of specifying Federal ownership of processing and disposal facilities. One could expect opposition from those concerned with State involvement and, after enactment, implementation could be significantly delayed until funds for capitalization were made available.

Summary

This alternative offers a highly effective program and maximum involvement of the private sector with a high Federal cost.

Alternative Twelve: Federal Responsibility, Facility Ownership, and Operation

This alternative would require legislation delegating to the Federal Government the responsibilities of satisfactorily managing hazardous wastes through promulgation and regulation of standards and directing the Federal Government to own and operate a system designed to meet these standards.

Advantages

1. This alternative offers the maximum level of effectiveness through a completely controlled national system.

2. Operation of the system would not be dependent upon the availability of private firms since actual financing of construction as well as operation would be conducted by Federal personnel.

Disadvantages

1. To implement this alternative would require a substantial increase in Federal cost.
2. Significant increases in Federal personnel would be required.
3. This alternative would preclude any involvement of the private sector in the management of hazardous wastes.
4. Meaningful participation by State solid waste management agencies would be precluded.

Degree of Federal Involvement

This alternative represents the maximum Federal involvement in the management of the nation's hazardous wastes.

Implementation Strategy

This alternative would require an extensive legislative package which would probably incur resistance from those favoring State participation and from those opposed to the Federal Government's role in waste management operations. Following enactment, significant delays could be expected in obtaining the necessary funds and in hiring and training new employees for operational responsibility.

Summary

The advantage of high effectiveness due to a totally internally controlled program would probably be offset by the high cost and significant increase in Federal employment typified by this alternative. This alternative also would preclude the involvement of private sector resources.

Institutional Alternatives Matrix

Some degree of overall net value quantification of the alternatives considered above is desirable. Table 39 illustrates a matrix analysis of the twelve alternatives weighted against six selected measurement criteria. These criteria are:

TABLE 39

INSTITUTIONAL ALTERNATIVE MATRIX

Alternative \ Measurement		Effectiveness	Equity	Federal Cost	Legislative Requirement	Increase in No. of Federal Employees	Incentive for Private Sector Involvement	Total
1	No Change in Existing Situation	10	3	1	1	1	5	21
2	State Responsibility and Standards	8	3	2	2	1	4	20
3	State Responsibility and Standards, Federal Subsidy	3	4	5	3	3	5	23
4	State Responsibility and Standards, Federal Tax Incentive	5	4	2	3	2	4	20
5	State Responsibility and Standards, Federal Guidelines	4	2	2	3	2	4	17
6	State Responsibility and Standards, Federal Guidelines, Subsidy	2	4	5	3	4	5	23
7	Federal Responsibility and Standards - No Management System	3	2	3	3	3	3	17
8	Federal Responsibility and Standards, Federal Subsidy	2	4	5	3	4	5	23
9	Federal Responsibility and Standards, Federal Tax Incentive	3	3	3	4	3	4	20
10	Federal Responsibility and Standards, Private Facility Operation, State Regulation	1	1	3	3	3	1	12
11	Federal Responsibility, Ownership, Contractor Operated	1	3	4	4	3	1	16
12	Total Federal	1	5	5	4	5	5	24

	Weight and Scale*	
• Effectiveness	1	Alternative offers greatest promise of protecting public and environment from hazardous wastes
	10	Alternative offers minimum promise of protecting public or environment from hazardous wastes
• Equity	1	Alternative distributes the financial burden directly to those who receive the greatest benefit from the wastes-producing operations
	5	Alternative distributes the financial burden to parties not directly benefiting from the hazardous wastes-producing operations
• Federal Cost	1	No additional funds required to implement alternative
	5	Significant additional Federal funds required to implement alternative
• Legislative Requirements	1	No additional Federal legislation required to implement alternative
	5	Major Federal legislative changes required to implement alternative
• Increase in Federal Employment	1	No new Federal employees required to implement alternative
	5	Significant increase in number of Federal employees required to implement alternative

---

*Note that effectiveness is rated on a scale of 1-10, giving this criterion twice the weight of the other criteria, which are judged on a scale of 1 to 5.

• Incentive for Private Sector Involvement	1	Alternative assures major involvement of private sector resources
	5	Alternative offers no incentive to involvement of private sector resources

Summary and Conclusions

Taking all things into consideration, the most effective institutional alternative would appear to be Alternative Ten, which combines Federal responsibilities and standards for hazardous waste management with the operation of privately owned waste processing, storage, and disposal facilities licensed and controlled by State governments. The overall advantage of this system is illustrated in the previous matrix.

The second most desirable approach is Alternative Eleven, which combines Federal responsibility and standard promulgation with Federal ownership of facilities and operation by the private sector under contract to the Federal Government.

LEGISLATIVE REVIEW - STATE LEGISLATION/REGULATIONS

To assist in developing perspectives on the "implementability" of a hazardous waste management system, a review of relevant legislation in sixteen States was conducted. The objectives of this effort were:

- To identify any legislative/regulatory situation at the State level that would constrain or facilitate a system.
- To determine whether any innovative legislative/regulatory mechanisms at the State level merit consideration at the Federal level.

Detailed law library searches and interviews with key officials were conducted in the following States:

Alabama
California
Colorado
Illinois
Kansas
Maine
Michigan
Nevada
New Jersey
New York
Oregon
South Carolina
Texas
Vermont
Virginia
Washington

These States were selected to provide a balance of:

- geographic distribution;
- proximity to sources of hazardous wastes;
- legislative posture regarding hazardous wastes; and
- environmental/conservation forces in the States.

Results of these interviews and law library searches are summarized in this section. Detailed findings on a State-by-State basis are given in Appendix N. Interview summaries were developed in a form highlighting the results obtained and the respective information sources, so that contacts can be reestablished in the future if necessary.

A matrix was prepared for each State, summarizing the following on an agency-by-agency basis: State agency responsibilities for hazardous wastes transportation; processing; disposal/storage; and miscellaneous functions. For each of the above functions, the matrix was completed (to the extent information was available) to indicate:

- what is being regulated, and how;
- how well it is being enforced, and by whom;
- potential constraints on a national system; and
- innovative legislative/regulatory approaches.

In conducting the research summarized in this section, particular emphasis was given to constraints that might cause delays in implementing a system for hazardous waste management. The various constraints considered include physical (geographical/geological) factors; existing or nonexisting facilities; existing or nonexisting regulations; the philosophy of the State government regarding control of the environment (local or regional groups as in California, or a more remote and centralized agency); safety requirements; the degree of interagency cooperation within the State and the extent of lateral communication among them; land use, including ownership patterns, size of property parcels, type of economy, type of population and its political philosophy and educational level; transportation factors; differing standards of adjoining States; diversity among agencies within a State; political hierarchy involved in administering existing regulations; and the status of Federal guidelines within the framework of the State (Have they been or are they boing to be adopted? Do State standards exceed Federal standards?).

As an overview, Table 40 summarizes the State-by-State research results. Key points include the following:

- Disposal of radioactive materials is regulated in all sixteen States surveyed. Transportation, processing, and storage is regulated in twelve States.
- One-half of the States surveyed have radioactive waste treatment/disposal facilities; less than half have facilities for other hazardous materials.
- Of the States surveyed, only six have industrial safety regulations.
- Fifteen States have adopted relevant DOT transportation regulations (Michigan has not).
- Land use regulations are predominantly under local control. Less than half of the States surveyed have State zoning.
- Air and water ambient quality standards are set in most States and are generally more stringent than Federal standards.
- Air and water emission standards are not as widely established as are ambient standards.
- Solid waste disposal and licensing is regulated in twelve of the sixteen States surveyed.
- Explosives regulation is spotty in comparison to other hazardous waste materials problem areas.
- Pesticides are the least regulated of any hazardous wastes. One-third of the States surveyed control their transportation or processing; one-half regulate their storage; most regulate their disposal.
- Existing highly regulated activities such as ambient air and water standards and radioactive disposal which are controlled by strict local standards probably provide the greatest potential for conflict in the establishment of a national disposal site system.

FEDERAL LEGISLATION/REGULATIONS

The purpose of the review of Federal legislative and regulatory mechanisms has been:

TABLE 40

SUMMARY OF STATE LEGISLATION SURVEY

	TRANSPORTATION		INDUSTRIAL SAFETY	PRESENCE OF EXISTING FACILITIES	
	DOT REGULATIONS	OTHER[a]	REGULATIONS FOR HANDLING HAZARDOUS MATERIALS	RADIOACTIVE	HAZARDOUS[b]
ALABAMA	YES	---	YES	YES	NO
CALIFORNIA	YES	YES	YES	---	YES
COLORADO	YES	NO	NO	NO	NO
ILLINOIS	YES	YES	---	YES	NO
KANSAS	YES	YES	---	YES	---
MAINE	YES	---	YES	NO	NO
MICHIGAN	NO	YES	YES	NO	YES
NEVADA	YES	NO	NO	NO	NO
NEW JERSEY	YES	---	DEV	YES	YES
NEW YORK	YES	---	YES	YES	YES
OREGON	YES	NO	NO	NO	NO
SOUTH CAROLINA	YES	YES	---	YES	DEV
TEXAS	YES	YES	---	YES	YES
VERMONT	YES	---	DEV	NO	NO
VIRGINIA	YES	---	DEV	NO	DEV
WASHINGTON	YES	NO	NO	YES	YES

[a] INCLUDES HAULING PERMITS, VEHICLE REGISTRATIONS, MATERIAL REGISTRATIONS, BILLS OF LADING, PLACARD ATTACHMENT, AND VEHICLE STANDARDS.

[b] INCLUDES PESTICIDES, TOXIC SUBSTANCES, AND OTHER CHEMICALS

	EXPLOSIVES REGULATIONS ON				LAND USE			
	DISPOSAL	TRANSPORTATION	PROCESSING	STORAGE	SHORELINE REGULATION	CITY ZONING	COUNTY ZONING	STATE ZONING
ALABAMA	---	---	---	---	---	---	---	---
CALIFORNIA	NO	YES	NO	YES	YES	YES	YES	NO
COLORADO	NO	NO	NO	NO	NO	YES	YES	YES
ILLINOIS	---	YES	---	---	YES	YES	YES	YES
KANSAS	YES	YES	YES	YES	---	---	---	---
MAINE	YES	YES	---	---	YES	YES	YES	DEV
MICHIGAN	YES	YES	---	---	YES	YES	YES	YES
NEVADA	YES	NO	NO	YES	NO	YES	YES	YES
NEW JERSEY	YES	YES	YES	YES	YES	YES	YES	DEV
NEW YORK	YES	YES	YES	YES	NO	YES	YES	DEV
OREGON	YES	YES	NO	YES	NO	YES	YES	YES
SOUTH CAROLINA	NO	YES	NO	NO	YES	YES	YES	DEV
TEXAS	---	---	---	---	---	YES	YES	YES
VERMONT	YES	YES	YES	YES	YES	YES	YES	YES
VIRGINIA	YES	YES	YES	YES	DEV	YES	YES	NO
WASHINGTON	YES	YES	NO	YES	YES	YES	YES	NO

TABLE 40 (Continued)

	RADIOACTIVE MATERIAL REGULATIONS ON				PESTICIDES REGULATIONS ON			
	DISPOSAL	TRANSPORTATION	PROCESSING	STORAGE	DISPOSAL	TRANSPORTATION	PROCESSING	STORAGE
ALABAMA	YES	YES	YES	YES	YES	YES	YES	YES
CALIFORNIA	YES	YES	YES	YES	YES	YES	YES	YES
COLORADO	YES	NO	NO	NO	NO	NO	NO	NO
ILLINOIS	YES	YES	YES	YES	YES	YES	YES	YES
KANSAS	YES	YES	YES	YES	YES	YES	YES	YES
MAINE	YES	YES	YES	YES	YES	NO	NO	NO
MICHIGAN	YES	YES	YES	YES	YES	YES	YES	YES
NEVADA	YES	YES	YES	YES	YES	NO	NO	YES
NEW JERSEY	YES	YES	YES	YES	YES	NO	NO	NO
NEW YORK	YES	YES	YES	YES	YES	NO	NO	NO
OREGON	YES	NO	NO	NO	YES	YES	NO	YES
SOUTH CAROLINA	YES	NO	NO	YES	NO	NO	NO	NO
TEXAS	YES	YES	YES	YES	NO	---	YES	YES
VERMONT	YES	YES	YES	YES	YES	NO	NO	NO
VIRGINIA	YES	YES	YES	YES	YES	NO	NO	NO
WASHINGTON	YES	NO	NO	NO	YES	NO	NO	NO

	SOLID WASTE		AIR QUALITY			WATER QUALITY		
	DISPOSAL REGULATIONS	LICENSING OF DISPOSAL SITES	EMISSION STANDARDS	AMBIENT STANDARDS	DISCHARGE PERMITS	EMISSION STANDARDS	AMBIENT STANDARDS	DISCHARGE PERMITS
ALABAMA	YES	YES	YES	YES	YES	YES	YES	YES
CALIFORNIA	YES	YES	YES	YES	YES	YES	YES	YES
COLORADO	YES	YES	---	---	---	---	---	---
ILLINOIS	DEV	YES	YES	YES	YES	YES	YES	YES
KANSAS	YES	YES	YES	YES	YES	YES	YES	YES
MAINE	DEV	NO	---	YES	YES	NO	YES	YES
MICHIGAN	YES	YES	YES	YES	YES	---	---	NO
NEVADA	NO	NO	YES	YES	YES	YES	YES	YES
NEW JERSEY	YES	YES	---	YES	YES	NO	YES	YES
NEW YORK	YES	YES	---	YES	YES	NO	YES	YES
OREGON	YES	YES	YES	YES	YES	YES	YES	YES
SOUTH CAROLINA	YES	YES	(YES)	(YES)	---	YES	YES	DEV
TEXAS	YES	YES	YES	YES	YES	YES	YES	YES
VERMONT	NO	NO	---	YES	YES	NO	YES	YES
VIRGINIA	YES	NO	---	YES	YES	NO	YES	YES
WASHINGTON	YES	YES	YES	YES	YES	YES	YES	YES

- to determine if any existing Federal legislation/ regulations will need to be changed to permit implementation of a hazardous wastes management system and

- to identify those areas where new legislation will be needed to implement a national system.

For purposes of information collection, review, and analysis the study was broken down into two primary elements. The first dealt with the substantive aspects (identification, treatment, disposal) and the second with the transportation aspects of hazardous waste management. The findings from each of these activities are described below.

Substantive Aspects

Federal legislation, executive orders, and regulations, as well as selected legislative proposals in the 92nd Congress, have been collected and reviewed with respect to possible relationships to the overall task of devising a national system for hazardous waste management. This phase of the legislative task was confined primarily to the areas of air, water and solid waste pollution control measures, legislation restricting the use and development of toxic substances, and Federal legislative proposals in the field of land use planning. Legislation and regulatory activities in the area of radioactive waste management were included in Chapter V.

No Federal legislation is in effect which directly bears upon the problems of collecting and disposing of nonradioactive hazardous wastes or the operation of a national system. Rather, existing legislation in many environmental areas would have an indirect effect upon the generation, identification, collection, transportation, storage and disposal of wastes which in various contexts might be defined as hazardous. Serious legislative proposals in the 92nd Congress, which are being renewed in the current Congress, would have the same potential effects. All such legislation is significant only to the extent that it calls attention to the need for comprehensive legislation designed to implement a system for hazardous waste management.

Existing Federal laws have been examined in the context of broad categories in the spectrum of the hazardous waste problem:

- identification/monitoring of waste streams;

- treatment; and

- storage and disposal.

The following is a summary of the tentative analysis of this material. No attempt has been made to summarize the voluminous and detailed material examined, but the most important Federal legislation is discussed. A more complete listing of the legislation reviewed will be found in Appendix N of this report.

Water

Water Pollution Control Act Amendments of 1972 (P.L. 92-500):

- Federal effluent standards for categories of industrial wastes
- National standards for control of new and existing point sources of pollution (Sec. 306)
- Preparation of list of toxic pollutants by EPA and development of effluent standards providing "an ample margin of safety" and pretreatment standards
- Authorized inspections, monitoring, reports by operators of point sources
- Federal enforcement by order, court action, civil and criminal penalties, citizen suits
- Oil and hazardous substance liability (Sec. 311), defining hazardous substances, penalties for discharge from onshore or offshore facilities
- Regulation, by permit procedure, of disposal to wells and ground water
- Pollutant permit program
- Exemption from NEPA requirements

Implications of the Act:

(1) Enforcement of effluent standards, periodically upgraded, may have the effect of forcing industries to turn to other means of treatment and disposal for hazardous wastes which would otherwise be discharged into conventional wastewater treatment systems.

(2) Inspection, monitoring, and reporting requirements, coupled with identification of toxic pollutants, will facilitate identification of sources of hazardous wastes, prediction of volume and content, and overall

planning development and location of disposal sites and treatment facilities.

(3) More stringent regulation of penalties for hazardous waste discharges, particularly from onshore facilities, may force use of nationally designated facilities.

(4) Research and development may carry over to the problems of hazardous waste disposal.

(5) Operation of hazardous waste systems would be subject to effluent standards imposed under this act.

(6) Enforcement provisions may provide useful experience for implementing hazardous wastes legislation.

(7) Federal efforts aimed at defining hazardous wastes, designating toxic substances, and setting standards for hazardous materials need to be integrated to avoid public confusion and to facilitate administration of regulations.

Marine Protection, Research, and Sanctuaries Act of 1972 (P. L. 92-532):

- Ocean dumping of radiological, chemical, or biological warfare agents or high-level radioactive wastes* are prohibited
- Permit procedure regulates ocean dumping of other material damaging to the environment; criteria established include feasibility of alternative land-based locations and methods of disposal
- Enforcement by court action, criminal penalties
- Comprehensive program of monitoring and research authorized

Implications of the Act:

(1) May force use of alternative means of disposal of hazardous wastes.

(2) Will provide experience in applying criteria for identifying hazardous material.

(3) Monitoring and research data may be useful in identifying hazardous wastes, sources, volume, etc.

---

*Note that the definition of high level wastes in this law is different from that used in Chapter V of this report.

Air

Clean Air Act, as amended, 42 U.S.C. 1857 et seq:*

- Air quality standards, State implementation plans
- Standards of performance by new stationary sources
- National emission standards for hazardous air pollutants
- Record keeping, inspections, and monitoring
- Research and development program

Implications of the Act:

(1) Enforcement of strict air quality standards may force industries to dispose of hazardous materials through alternative means, possibly by a nationally designated system.

(2) Record keeping, inspections, and monitoring may produce useful data in identifying sources and volumes of hazardous wastes produced.

(3) Research and development programs may produce carryover data.

(4) Operation of system would be subject to air quality standards established under this Act.

Pesticides

Federal Insecticide, Fungicide, and Rodenticide Act, 7 U.S.C. 135 et seq., as amended by the Federal Environmental Pesticide Control Act of 1972, (P. L. 92-516):

- Registration of pesticides, with supporting data as to formula, proposed use
- Classification as to use, labeling, and warnings

---

*Processing and disposal sites for hazardous wastes would also be required to comply with future new source performance standards (Section 111 of the Clean Air Act Amendments) and future hazardous pollutant standards (Section 112). As an example, the promulgated national emission standard for beryllium is already applicable to special waste disposal incinerators.

- Registration of producers, disclosure of types, and amounts of pesticides produced
- Record keeping and inspections
- Stop sale, use or removal orders, seizure, and disposal
- Disposal and transportation
- Research and monitoring
- Concurrent State authority so long as State standards at least meet Federal standards

Implications of the Act:

(1) Regulation of the production and use of pesticides could have a direct effect on the volume of hazardous wastes to be handled by a national hazardous waste system.

(2) Registration and disclosure, as well as requirements, inspection, and record keeping, will facilitate identification of hazardous wastes, source locations and volumes.

(3) Procedures and regulations for the disposal or storage of pesticides under Section 19 of the Act may be directly related to the need for hazardous waste disposal sites.

(4) Research and monitoring programs may produce carryover data.

Toxic Substances

Toxic Substances Control Act of 1972, S. 1478 (No final action by Congress in 1972)

- Definitions and EPA test standards relating to protection of health and environment
- Premarket screening of new chemical substances
- Restrictions on use or distribution of chemical substances
- Criteria to include effects of substances on health, environment, benefits for various uses, magnitude of exposure, and availability of less hazardous substitutes

- Seizure of offending substances in case of "imminent hazard"

- Administrative inspections and reports required from manufacturers and processors, containing estimates of quantities, description of byproducts resulting from production, processing, use of disposal

- Research and monitoring

Implications of the Act:

(1) Use and distribution regulations could take into account problems of disposing of hazardous substances or byproducts and thus directly affect the nature and volume of hazardous wastes requiring disposal.

(2) Definitions, test standards, and criteria would provide useful experience and carry-over to regulation of hazardous wastes in general.

(3) Premarket screening, inspections, and reports from manufacturers and processors would provide useful data to facilitate identification, source location, and volume of hazardous wastes.

(4) Exemptions of substances subject to other Federal acts (Sec. 110) and provisions for coordination with other Federal agencies may prove to be instructive.

(5) Research and monitoring may provide carry-over data.

(6) Section 122 provides for Federal pre-emption of State regulation "other than a total ban."

Land Use

Federal Lands: The possibility that Federally-owned land might be used as site locations for all or part of a hazardous waste disposal system has been considered, and the numerous Federal laws pertaining to Federally-owned lands under the jurisdiction of a wide variety of Governmental agencies, principally the Bureau of Land Management in the Department of the Interior, were initially reviewed, including proposed S. 2401, the National Resource Lands Management Act of 1972, and H.R. 7211. It was concluded, however, that to the extent such sites are to be considered, new legislation implementing a hazardous waste disposal system would need to specifically provide for the use of such lands, establish standards of land use, etc., presumably overriding any existing land use restrictions or Federal agency jurisdictional conflicts. (See, however, discussion of NEPA below).

State and Local Land Use Restrictions: It was also tentatively concluded that new Federal implementing legislation would override conflicting State and local land use regulations. However, recent Federal legislative activity in the field of land use and land management is worth noting.

Land Use Policy Planning Assistance Act of 1972, (S. 632 passed Senate September 19, 1972, no action in the House, reintroduced as S. 268 on January 9, 1973):

- Grants to States for development of comprehensive land use planning programs
- Federal projects to be consistent with State plans "except in cases of overriding national interest"
- Disclaimer of any intent to alter existing Federal-State-local relationships as to use or control of lands

Coastal Zone Management Act of 1972 (P.L. 92-583):

- Grants to coastal States for developing management program for coastal land and water resources
- Administrative grants
- Coordination and cooperation between Federal agencies
- Emphasis on comprehensive area-wide land planning and land management programs at the State level
- Section 307, paragraphs (e), (f) and (g), in effect provide that requirements of Federal water and air pollution legislation and any Federally supported national land use program will override a State's coastal zone management program

Environmental Impact

National Environmental Policy Act of 1969 (P.L. 91-190):

Operation of a national disposal sites system pursuant to Federal implementing legislation would be subject to NEPA, and in particular, the environmental impact statement requirements, although under CEQ guidelines published April 23, 1971, "environmentally protective regulatory activities concurred in or taken by" EPA would not require impact statements. Worth noting, however, is the limited exemption from the requirements of NEPA contained in Section 511(c) of the Federal Water Pollution Control Act Amendments of 1972, discussed above.

Legislative References

National Environmental Policy Act of 1969 (42 USC 4321-4347).

Environmental Quality Improvement Act of 1970 (42 USC 4371-4374).

Environmental Pollution Study Act (42 USC 4391-4395).

Executive Order 11514, Protection and Enhancement of Environmental Quality, March 5, 1970, 35 F.R. 4247, 42 USC 4321 note.

Executive Order 11507, Prevention, Control and Abatement of Air and Water Pollution at Federal Facilities. (Feb. 4, 1970, 35 F.R. 2573, 42 USC 4331 note).

Executive Order 11523, National Industrial Pollution Control Council, April 9, 1970, 35 F.R. 5993, 42 USC 4321 note.

Guidelines for Federal Agencies under NEPA--Issued by CEQ, April 23, 1971.

Federal Insecticide, Fungicide and Rodenticide Act of 1971 (7 USC 121, 135, 135a-k).

Studies of Effects (on fish and wildlife) in Use of Chemicals (16 USC 742d-1).

Federal Food, Drug and Cosmetic Act (21 USC 301-392, [particularly 342, 343, 346]).

Federal Hazardous Substances Labeling Act, as amended (15 USC 1261-1274).

Poison Prevention Packaging Act of 1970 (7 USC 135; 15 USC 12161, 1471-1476; 21 USC 343, 352, 353, 362).

Federal Water Pollution Control Act, as amended (33 USC 1151-1175).

Executive Order 11548, Delegation of Presidential Functions, July 20, 1970 (35 F.R. 11677, 33 USC 1151 note).

Rivers and Harbors Act of 1899 (Refuse Act) (33 USC 401, 403-4, 409-9, 411-15).

Executive Order 11574, Refuse Act Permits, December 23, 1970.

Water Resources Research Act of 1964 (42 USC 1961-1961c-7).

Water Resources Planning Act (42 USC 1962-1962d).

Fish and Wildlife Act of 1956 (15 USC 713c-3, 742a-5).

Clean Water Restoration Act of 1966 (33 USC 431-437, 466a, 466c-1 to 466e, 466g, 466j, 4661-466n).

The Clean Air Act (42 USC 1857-1857-1).

Executive Order 11602, June 29, 1971 (36 F.R. 12475, 42 USC 1857h-4 note).

Solid Waste Disposal Act, as amended (42 USC 3251-3259). (Includes National Materials Policy Act and Resource Recovery Act of 1970).

Mining and Minerals Policy Act of 1970 (30 USC 21a).

Land Conservation and Land Utilization (7 USC 1010).

Recent Legislation

Rural Development Act of 1972 (H.R. 12931 - P.L. 92-41). Signed into law, August 30, 1972.

Land Use Policy and Planning Assistance Act of 1972 (S. 632). Passed Senate, September 19. No further action.

National Land Policy, Planning & Management Act of 1972 (H.R. 7211 and S. 2401). S. 2401 reported, S. Rpt. 92-1163, September 18, 1972. No action in the House.

Safe Drinking Water Act of 1972 (S. 3994). Passed Senate, September 28. No further action.

Water Pollution Act Amendments of 1972 (S. 2770). Passed over Presidential veto, October 18, 1972. Conference Report H. 92-1465.

Coastal Zones Management Act of 1972 (S. 3507; H.R. 14146), P.L. 92-583. Passed House and Senate, October 12, 1972.

Marine Protection Research & Sanctuaries Act of 1972 (Ocean Dumping). (H.R. 9727) (P.L. 92-532). Conference Reports adopted October 13, 1972.

Federal Environmental Pesticide Control Act (H.R. 10729) (P.L. 92-516). Conference Report adopted October 5 (Senate) and October 12 (House).

Environmental Data System (H.R. 56). Final passage, October 6, 1972. Vetoed.

Toxic Substance Control Act (S. 1478). Passed with House amendments, October 14, 1972. No final action.

Oil Pollution Act Amendments of 1972 (H.R. 1562). Passed House, October 11 (H. Rpt. 92-1486). No further action.

Rivers & Harbors - Flood Control (S. 4018). Conference Report adopted August 12 (Senate) and October 13 (House). Vetoed.

Transportation Aspects

Federal legislative/regulatory activities relating to the transportation of hazardous wastes are summarized according to relevant administrative structures and the inadequacies that exist within these structures.

Administrative Structure

Originally, Congress vested in the Interstate Commerce Commission the authority to formulate regulations for the safe transport of dangerous articles in interstate and foreign commerce [18 USC 831-835 (1940)]. The heart of the Act was Section 834 (a), which was binding upon all carriers and shippers engaging in interstate commerce.

With the creation of the Department of Transportation (DOT) the functions of the ICC under this section were specifically transferred to the Secretary of Transportation in 1966. To administer these provisions, the Coast Guard, Federal Highway Administration, and the Federal Railway Administration were drawn together, as semi-autonomous bodies, within DOT. These "modal" administrations have jurisdiction to make and enforce regulations concerning transportation of hazardous materials.

To promote uniform regulations and provide general policy-making machinery to serve these administrations, the DOT created in 1971 the Office of Hazardous Material (OHM) and the Hazardous Materials Regulation Board (HMRB or "the Board"), which reports directly to the Secretary.

The OHM is charged with research in formulating regulations, coordinating their scope and applicability to the various modes of transport, and advising the HMRB; it has no enforcement power of its own, however, and in effect serves as an "input" organ to rule-making. OHM also acts for DOT in carrying out Section 302 of the Hazardous Materials Transportation Control Act (P.L. 91-458, 1970), which calls for evaluation of dangers involved in shipping hazardous materials and establishment of a central reporting system to aid in meeting emergencies which arise.

Acting as a deliberative body at the policy-making level, the HMRB likewise has no enforcement jurisdiction. It is composed of a representative designee from each modal administration and a representative of OHM sitting as secretary and chairman. The rule-making procedures of HMRB are found in 49 CFS 170.1 and summarized below.

The rule-making procedure is initiated at the motion of any one of the members of the Board, although the Board will consider recommendations of other government agencies or other interested persons.

Once the procedure is initiated, any person can participate in the proceedings by submitting written information or views to the Board. Further, the Board may allow any person to participate in additional rule-making procedures such as informal meetings or hearings.

At any time, any person (e.g., EPA) may petition the Board to initiate the rule-making procedure to issue, amend, or repeal a rule. Each petition must include the text or substance of the proposed rule or change, the interest of the petitioner in the action, and information to support the requested action. Petitions are submitted to the Secretary of the Board.

Once a petition is submitted it is considered by the Board along with the information submitted by the petitioner and any other available pertinent information. Unless the Board directs otherwise, there is no public hearing or argument on the petition prior to its disposition. If the Board finds that the proposal provides for adequate safety and is otherwise justifiable, it will initiate the rule-making procedure. If the Board finds that the rule does not provide for adequate safety or is not justifiable otherwise, the petition will be denied and the petitioner informed of the reasons for denial. This procedure for processing covers petitions for special permits, waivers, and special exemptions for any regulations.

Once the rule-making procedure has been initiated a notice of proposed rule-making will be issued and interested persons will be invited to participate. If the Board finds that for good cause notice is impracticable, unnecessary, or contrary to public interest and so states in the preamble of the rule, no notice will be issued. Normally, the Board will allow at least thirty days for comment on each notice. Unless the Board determines otherwise, interpretive rules, general policy statements, and organizational, procedural, or practice rules will become final without notice or other rule-making proceedings. Where notice has been issued, all timely comments (including late-filed ones as practicable) will be considered before final action is taken on a proposal.

After notice has been issued, the Board may initiate any other rule-making procedures it finds necessary; the hearing is a fact-finding proceeding and not an adversary one.

Final rules are published in the Federal Register; all parties subject to them will be named and served with a copy. Furthermore, a regulation is applicable to a mode of transportation only if the Board member representing that mode signs it.

The National Transportation Safety Board is an independent government agency housed within DOT. Statutes, functions, duties, and responsibilities relating to the determination of the causes of transportation accidents are assigned to NTSB.

The Bureau of Surface Transportation Safety, the key office within NTSB, investigates rail, highway, marine, and pipeline accidents. It has no field force but draws chiefly upon the Bureau of Motor Carrier Safety and Bureau of Railroad Safety for investigations.

The independence of the NTSB is part of a long standing Federal policy to separate rule-making from accident investigation. This in theory allows the NTSB to be a critic on transportation safety and gives it a freer hand to initiate accident investigations, request accident information from other agencies, and undertake special studies relating to transportation safety. However, no action taken by NTSB is binding; its function is to be a "feedback loop" to the entire Federal transportation system, not a formulator of policy.

All other modes (e.g., the Bureau of Motor Carrier Safety and the Bureau of Railroad Safety) have accident reporting and investigation which complement the rule-making procedures with the mode. Such operation is unlike the multi-modal, freewheeling critical function of the NTSB.

The NTSB is supreme in the field of accident investigation and in cases where it has delegated its authority, as to the Bureau of Motor Carrier Safety and the Bureau of Railroad Safety, under 14 CFR 400.43 it can preempt investigation of accidents which are catastrophic in magnitude, of general public interest, or which involve questions of broad national interest or unique technical problems.

NTSB has long been a critic of hazardous materials regulation and has investigated many hazardous materials accidents. It is an important watchdog in the present system.

Viewed as a whole, the regulation of hazardous materials transportation by DOT has three phases: rule-making by the HMRB and OHM; investigation; and enforcement by the several modal adminstrations. All three phases are, of course, carried out within the scope of DOT's general jurisdiction. However, other agencies control various aspects of hazardous materials, as mentioned below.

Regulations

Each of the four modal administrations has power to adopt and enforce the regulations promulgated under the rule-making procedures of HMRB. At present, they are not uniform across the spectrum of transport modes owing to the obviously differing dangers, standards of care, and requirements of each. Implementation of a national hazardous waste management system would make standardization of regulations almost imperative; in fact, this is one priority of the OHM currently under consideration.

There presently exists a proposal to combine existing regulations within one title to eliminate duplication and superfluous material and to better coordinate with international standards for hazardous materials transportation.

While the regulations themselves are relatively diffuse, the problem of enforcement is larger still. The FAA and USCG may directly enforce their regulations, while FRA and FHWA must work through the Department of Justice. It appears that enforcement of highway and rail regulations is more difficult due to the absence of specifically defined terminal points in shipment. The enforcement problem is aggravated further by the general lack of funds and personnel to carry out investigations, with the result that agency clientele are largely self-policing. However, since the potential for economic loss and civil liability resulting from negligent transportation of hazardous wastes is great, carriers generally obey regulations to the general satisfaction of DOT.

Interested Agencies: Jurisdiction

The DOT Act vests DOT with the power to regulate shippers and carriers in interstate commerce. Any materials in the interstate "patterns" of transportation are within the jurisdiction of DOT (each mode administering its own regulations). Because the subject of the hazardous materials regulation is "shippers and carriers", jurisdiction has been defined according to the nature of the carrier rather than on the basis of the movement of hazardous materials. If the carrier generally engages in interstate transportation, even intrastate shipments by that carrier are within DOT regulatory jurisdiction. However, DOT lacks jurisdiction if the shipment is made within a State by a carrier which is not licensed interstate.

Within the interstate pattern of transportation, DOT has authority to regulate storage of hazardous materials. This is true regardless of whether the materials remain in the transportation vehicles (tank cars) or are removed and stored in a facility of the carrier. During storage, other agencies often have an interest in the safety of the materials and the individuals near them. The Alcohol, Tobacco and Firearms (AT&F) Division of the Department of the Treasury regulates the storage of explosives, deriving its authority from the Organized Crime Control Act of 1970.

If a carrier regulated by DOT is carrying explosives, Section 181.141 of the Organized Crime Control Act disallows AT&F from regulating. Generally, AT&F has no jurisdiction over explosives in the hands of a U. S. agency or a State. AT&F has published a list of the explosive materials with which it is concerned. Some of the same materials are regulated by DOT; DOT regulations are transportation-oriented, however, and AT&F regulations are storage-oriented. For this reason DOT has often relied on the AT&F regulations in the storage area.

The Occupational Safety and Health Administration (OSHA) is concerned with regulations to protect the health and safety of workers in the storage area (Occupational Safety and Health Act of 1970). While OSHA regulations are aimed solely at worker protection, they have often been the only regulations with jurisdiction at a particular instance in the transportation process.

The policy of OSHA and the limit of its authority is to regulate only when no other agency has done so. Such inaction by the other agencies may be due to either lack of resources or lack of jurisdiction. OSHA, therefore, must first determine whether another agency is regulating in the area in question.

In doing so, it often relies on the work of individuals in the other agencies. OSHA regulations are sometimes referred to by DOT in its regulatory processes and, on some occasions, interagency meetings have been organized to coordinate the regulations and to fill in any gaps. OSHA, AT&F and DOT regulations are often used in conjunction through these coordination agreements.

Inspection of Containers Before Transit

There is little question that DOT has authority to inspect containers being stored by the carrier in its facilities prior to transit. More uncertainity exists concerning inspection of materials awaiting shipment at the manufacturing plant where they are produced. Attorneys for DOT feel that the Department possesses such authority, but it is rarely used. Inspection is done on a very limited basis by OHM field inspectors and inspectors from each mode of transportation. No challenge has been made to DOT authority in this area.

To clear up uncertainties, however, the Office of Management and Budget is currently reviewing proposed legislation granting DOT power to inspect all carrier and manufacturer (of hazardous materials) facilities. If the legislation is passed, much of this "gray area" will be clarified. Presently, in case of a lack of regulation and inspection both OSHA and AT&F have authority to regulate and inspect all facilities of manufacturers of hazardous materials within their jurisdiction.

Container leaks constitute the major cause of hazardous material spills. DOT's regulatory power only covers interstate shippers and carriers and does not presently extend to regulating container manufacturers.

The Federal Government is empowered, via 49 CFR, Section 388, to enter into cooperative agreements with the States providing for the adoption of hazardous materials regulations by the HMRB. Most States have adopted the regulations of the Federal Highway Administration as they pertain to transporting hazardous materials. Consequently, local intrastate carriers are regulated by State law which specifically incorporates the Federal legislation.

Inadequacies of the Present Federal System of Controlling Transportation of Hazardous Wastes in Interstate Commerce

As constituted, the control network outlined above presents a fairly typical portrait of bureaucratic response to a complicated problem. It follows quite naturally that the conventional shortcomings of Federal agencies are built into this system as well. A general synopsis could continue indefinitely; however, below are several particular items, learned from this investigation, which should be considered when constituting transportation management in the context of a system of national disposal sites.

Lack of Resources

Currently one of the major inadequacies is resources. Almost every aspect of the transportation of hazardous materials reflects this lack both at the State and Federal levels, in terms of money, manpower, expertise, and research and development.

At the Federal level, HMRB, which has the authority to promulgate regulations regarding transportation of hazardous materials, does not have the resources to conduct its own research and development programs (to determine, for example, the adequacy of a container). Industry and carriers are the motivating forces behind the introduction of new regulations and new technical means for transportation. If a container or carrying method is inadequate, HMRB can only move to prevent future "incidents" once an inadequacy in the field (i.e., an accident) has been reported. The staff is hopelessly inadequate to determine whether or not shippers are in fact enforcing regulations concerning containers and methods of handling. The manpower shortage in HMRB is impeding reformation of its current set of substantive regulations. OHM is currently three years behind in rule-making due to this general lack of technical staff and resources.

Within each modal office a similar lack of manpower exists. For instance, the Bureau of Motor Carrier Safety with its field staff of just over one hundred cannot hope to enforce its compliance standards.

Within the investigative field, similar lacks show up in the small number of accident investigations conducted each year. The Bureau of Motor Carrier Safety with its staff performs about 275 such studies; the independent NTSB with its lack of field staff managed 42 in 1971. Neither of these groups suffers from lack of expertise, however.

Lack of Coordination Between DOT and Other Agencies

While a careful search of the statute books brings to light few, if any, statutory gaps, it is apparent that numerous regulatory gaps exist in the present structure. Many accident reports prepared by NTSB have revealed a lack of control at such points as the transportation/receiving interfaces. No careful coordination nor effective communication has been found, in this case, between OSHA (and its employee safety role) and DOT. Presently, because of this lack of consultation OSHA cannot determine with accuracy when another agency is regulating a particular situation. In addition, agencies which set their own employee safety standards are often unaware of more stringent and better-researched OSHA standards. There is no effort by the agencies to spell out clearly the specific areas to be covered by their regulations and administration.

Inadequacies in Substance of Present Standards

The substance of the present hazardous materials transportation regulations is inadequate, both in terms of a standard risk level and of environmental losses (including human lives). The principal difficulties with current regulations are:

- there is no clear, uniform policy objective among DOT's modal regulations;
- there are discrepancies in apparent levels of risk permitted by regulation among the modes and among different commodities; a shipment of a certain chemical under current standards may involve a different level of risk according to whether it is shipped by rail or truck, or different chemicals may be implicitly allowed different risk levels;
- inadequate methods or criteria exist for determining and comparing the merits of proposed changes in regulations, both before and after promulgation. For example, present regulations are structured around preventing the escape of a commodity from its container, ignoring other factors which affect the risk, such as changes in the probability of an incident and the severity of the consequences should an escape occur;
- the lack of input by affected parties means that regulations are prompted by actions of shippers and carriers; there is no consultation with the parties-at-risk (such as a bystanding population) and environmental input into the system.

Lack of Uniform Investigatory Processes

At present there are investigative branches within each mode which concentrate on accidents of a general nature but not on hazardous materials involved in accidents. Also, each modal investigative process is hampered by a small staff, so that only a fraction of the accidents the agencies would like to handle are reviewed.

The only intermodal investigatory agency is the NTSB. The NTSB has serious deficiencies also.

- It lacks the resources to investigate in depth a reasonable number of accidents. For example, in 1971 there were 1,877 marine fatalities, 45 pipeline fatalities, 615 railroad fatalities, and 1,360 rail-highway grade crossing fatalities, but NTSB reported on a total of 42 accidents.
- Efforts to make the accident investigations conducted and reported by the States uniform have been unsuccessful.
- Suggestions have been made that the recommendation power is not enough, that some kind of binding effect should be given the NTSB reports. The NTSB feels that industry and government have been cooperative. Further, it cites figures that indicate a majority of its recommendations were acted upon favorably; for example, of 176 recommendations in the surface field, 130 were adopted in whole or in part. Finally, they feel that the competence level of their reporting is raised by the need to write reports that will stand up under fire from antagonistic parties; the reports stand or fall on their own merits and do not lean on statutory force. However, there is evidence that many of their suggestions have not been acted upon, since their reports frequently cite the fact that some aspect of the accident need not have occurred if a previous NTSB recommendation had been implemented.
- The fact that NTSB must "borrow" investigators from DOT leads some to the conclusion that these investigators will not produce a report critical of the home agency.

In short, there is no pressure concerted against the problem of accidents involving hazardous materials in the whole Federal sphere. The only intermodal agency, NTSB, has serious manpower and enforcement deficiencies.

Lack of Information to the States and Municipalities

Information is not being dispersed to State and municipal bodies and to many companies which work with hazardous substances. Many State and local emergency personnel (firemen, policemen, rescue workers, etc.) are not qualified to safely and efficiently control hazardous material accidents. This is especially true in areas removed from metropolitan areas where waterways, highways and rail lines carry large amounts of hazardous substances.

Lack of Information to Industry

Many companies which use hazardous substances or which transport hazardous materials in their manufacturing processes are not aware of the properties of the materials with which they work. These conditions pose safety problems, especially evident in the mixing of incompatible hazardous chemicals.

There is, in short, inadequate manpower, funds and expertise to administer hazardous material regulatory programs in the United States. Many States do not have control and implementation offices with trained hazardous material specialists continuously monitoring the flow of hazardous materials within the State.

Enforcement Problems

Two separate enforcement mechanisms currently exist: FAA and the Coast Guard have direct jurisdiction while FRA and FHWA must work through the Department of Justice. These do not accurately reflect the distinct problems of enforcement particular to each modal adminstration.

SUMMARY

Policy-Making

Since a national system for hazardous waste management is concerned with protecting the environment as well as the health and safety of individuals, environmental policy concerns must be considered in dealing with transportation incident to the operation of such a system. Currently, regulations developed by OHM and rule-making procedures of HMRB are aimed primarily--perhaps exclusively--at ameliorating the so-called "acute" problems which may arise from mishaps during shipment of hazardous materials, namely, the immediate impact on persons and their property. This approach, of course, is consistent with the general purpose of DOT's exercise of authority in the promotion of safety; however, it falls short of compliance with the mandate of Section 103 of the National Environmental Policy Act that all agencies review their regulations and procedures to determine inadequacies and deficiencies which may prohibit full compliance with the policy and purpose of protecting the environment. Thus, a comprehensive reevaluation of the problems involved in transportation of hazardous wastes and extensive research into environmental impact is needed. A specific example will illustrate the result of such an approach: in formulating regulations for containers used to ship a particular hazardous substance, regard must be paid to the adequacy of such containers as disposal units.

Lack of Resources

DOT has the greatest amount of resources and expertise at present to regulate the hazardous waste transportation system. Costs would be too great for another agency to take over regulation. However, for this purpose, DOT needs more financial resources devoted to testing labs, research, and development of regulations and more qualified personnel, educational grants, and training scholarships. Personnel increases are especially needed in the areas of enforcement, investigation, and inspection. States should also be provided with funds sufficient for compliance, as well as aided in developing training programs for their personnel.

Coordination

Establishment of a commission within DOT or EPA to monitor the ordinances of all the different agencies which regulate hazardous materials should be considered. The commission would promote the free exchange of information on a continuing basis and would oversee the entire hazardous materials regulatory scheme. Initial implementation should include a detailed description of each agency's jurisdiction, so that any regulatory gaps could be discovered. One particular area in need of coordination is employee safety, as OSHA will regulate only where EPA does not.

At present no one person oversees the work of OHM and the HMRB. While one might question adding another layer of administration to a rule-making authority, the separation of rule-making from investigating authority has worked well in the limited role with NTSB, since that agency is free to criticize where needed without fear of intra-agency reprimand. An overseer of independent status could also aid in coordinating, by making recommendations as to project definition, transfers of power and information between modes, and implementation processes.

Substantive

Change in present regulations dealing with hazardous material transportation to reflect explicit risk level concepts should be considered. OHM recognizes these lacks, as seen in the DOT Second Annual Report. Focus should also be placed upon prospective spill possibilities; the present system based on accident reporting should not be the main motivating device to change inadequate regulations. Legislation must also deal with final disposal of containers used to transport hazardous materials.

A means must be created for EPA to provide effective and essential input into DOT rule-making hearings and to generally keep current on the adequacy of DOT regulations. This role of EPA is especially vital when one considers that under the present system none of the parties providing input is concerned with safety at the disposal sites.

FINANCING CONSIDERATIONS

At the initiation of this program, a requirement existed to develop a financing plan for national disposal sites for hazardous wastes. This portion of the work was to:

> *develop equitable financing plans for land acquisition, final design, construction, and operation of a system of national disposal sites. Incentives such as tax credits, subsidies, loans, etc., will be evaluated to encourage use of the sites. The costs involved with establishing and operating these sites may be distributed among any combination of Federal, State, and local governments, industry, and users of the disposal sites.*[7]

As the program evolved, it became apparent that implementation of a hazardous waste management system would not necessarily involve a system of Federal sites. Thus, the need for extensive effort in development of financing plans was markedly diminished. It was apparent that with private sector ownerships and operation, normal financial systems would be brought into play.

Since the amount of effort in this program devoted to financing considerations was limited, no firm conclusions were reached. The findings, to the extent they were developed, are given in Appendix V.

CHAPTER VIII

REFERENCES

1. Resource Recovery Act. Public Law 91-512, 91st Cong., H.R.11833, Oct. 26, 1970. [Washington, U.S. Government Printing Office, 1970.] 9 p.

2. U.S. Congress. Federal Water Pollution Control Act Amendments of 1972. Sec.311. Oil and hazardous substance liability. Public Law 92-500. Washington, Oct. 18, 1972. [p.47-56.]

3. U.S. Congress. Federal Environmental Pesticide Control Act of 1972. Public Law 92-516. Washington, Oct. 21, 1972. [27 p.]

4. U.S. Congress. Marine Protection, Research, and Sanctuaries Act of 1972. Public Law 92-532, 92d Cong., H.R.9727. Washington, Oct. 23, 1972. 12 p.

5. Booz, Allen Applied Research, Inc. A study of hazardous waste materials, hazardous effects, and disposal methods. U.S. Environmental Protection Agency Contract No. 68-03-0032. [Bethesda, Md.], June 30, 1972. 3 v.

6. Funkhouser, J. T. Alternatives to the management of hazardous wastes at national disposal sites. U.S. Environmental Protection Agency Contract No. 68-01-0556. [Cambridge, Mass.], Arthur D. Little, Inc., May 1973. 2 v.

7. Sax, N. I. Dangerous properties of industrial materials. 3d ed. New York, Van Nostrand Reinhold Company, 1968. 1,251 p.

8. Meidl, J. H. Explosive and toxic hazardous materials. Beverly Hills, Glencoe Press, 1970. 387 p.

9. Selected problems of hazardous waste management in California. Report of the Hazardous Wastes Working Group. Governors' Task Force on Solid Waste Management, Jan. 1970. 39 p.

10. Booz, Allen Applied Research, Inc. A study of hazardous waste materials, hazardous effects and disposal methods. v.1. U.S. Environmental Protection Agency Contract No. 68-03-0032. [Bethesda, Md.], June 30, 1972.

*11. Abstract of Proceedings; Hazardous Polluting Substances Symposium, U.S. Department of Transportation, Coast Guard, New Orleans, Sept. 14-16, 1970.

---

*All references except those marked with asterisks have been verified by the Office of Solid Waste Management Programs.

12. Dawson, G. W., A. J. Shuckrow, and W. H. Swift. Control of spillage of hazardous polluting substances. U.S. Environmental Protection Agency, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, 1971. [410 p.]

13. Fire protection guide on hazardous materials. 4th ed. NEPA No. SPP-1A. Boston, National Fire Protection Association, 1972.

*14. Dangerous chemicals code. Los Angeles Fire Department.

15. Christensen, H. E., ed. The toxic substances list. Rockville, Md., U.S. Department of Health, Education, and Welfare, 1972. 563 p.

16. Threshold limit values of airborne contaminants. Cincinnati, American Conference of Governmental Industrial Hygienists, 1970. 27 p.

17. Committee on Hazardous Materials. Evaluation of the hazard of bulk water transportation of industrial chemicals; a tentative guide. Washington, National Academy of Sciences, 1970. 25 p.

18. Smyth, H. F., Jr., C. P. Carpenter, and C. S. Weil. Range-finding toxicity data, list IV. A.M.A. Archives of Industrial Hygiene and Occupational Medicine, 4:119-122, 1951.

19. Ottinger, R. S. Recommended methods of reduction, neutralization, recovery, or disposal of hazardous waste. U.S. Environmental Protection Agency Contract No. 68-03-0089. [Redondo Beach, Calif.], TRW Systems Group, Inc., June 1973. (Unpublished data.)

*20. Kneip, T. J., and G. J. Lauer. Progress in analytical chemistry. G. Ewing, ed. New York, Plenum Press, 1973.

21. Polikarpov, G. G. Radioecology of aquatic organism; the accumulation and biological effect of radioactive substances. New York, Van Nostrand Reinhold Company, 1966. 314 p.

22. National electrical code. NFPA No. 70. Boston, National Fire Protection Association, 1971.

23. Christensen, H. E., ed. The toxic substances list. Rockville, Md., U.S. Department of Health, Education, and Welfare, 1971. 512 p.

24. Smyth, H. F., Jr., C. P. Carpenter, C. S. Weil, U. C. Pozzani, J. A. Striegel, and J. S. Nycum. Range-finding toxicity data, list IV. American Industrial Hygiene Association Journal, 30(5):470-476, Sept./Oct. 1969.

25. Smyth, H. F., Jr., C. P. Carpenter, C. S. Weil, U. C. Pozzani, and J. A. Striegel. Range-finding toxicity data; list VI. American Industrial Hygiene Association Journal, 23:95-107, 1962.

26. Smyth, H. F., Jr., C. P. Carpenter, C. S. Weil, and U. C. Pozzani. Range-finding toxicity data, list V. A.M.A. Archives of Industrial Hygiene and Occupational Medicine, 10:61-68, 1954.

27. Smyth, H. F., Jr., C. P. Carpenter, and C. S. Weil. Range-finding toxicity data, list III. Journal of Industrial Hygiene and Toxicology, 31:60-62, 1949.

28. Smyth, H. F., Jr., J. Seaton, and L. Fischer. The single dose toxicity of some glycols and derivatives. Journal of Industrial Hygiene and Toxicology, 23:259-268, 1941.

29. Smyth, H. F., Jr., and C. P. Carpenter. Further experience with the range-finding test in the industrial toxicology laboratory. Journal of Industrial Hygiene and Toxicology, 30:63-68, 1948.

30. Smyth, H. F., Jr., and C. P. Carpenter. The place of the range-finding test in the industrial toxicology laboratory. Journal of Industrial Hygiene and Toxicology, 26:269-273, 1944.

31. Standard methods for the examination of water and wastewater. 13th ed. New York, American Public Health Association, 1971. 874 p.

32. McKee, J. E., and H. W. Wolf, eds. Water quality criteria. 2d ed. California State Water Quality Control Board Publication No. 3-A. Sacramento, 1963. 548 p.

33. Battelle Columbus Laboratories. Effects of chemicals on aquatic life. Water Quality Criteria Data Book. v.3. U.S. Environmental Protection Agency, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, May 1971. [526 p.]

*34. Oil and hazardous materials technical assistance data system. U.S. Environmental Protection Agency, Division of Oil and Hazardous Materials, Office of Water Programs.

*35. Personal communication. Ralph Wands, Director of Advisroy Center on Toxicology, National Academy of Science, 1973.

36. Epstein, S. S., and M. S. Legator, eds. The mutagenicity of pesticides: concepts and evaluation. Cambridge, MIT Press, 1971. 220 p.

37. Arthur D. Little, Inc. Organic chemical pollution of freshwater. Water Quality Criteria Data Book. v.1. U.S. Environmental Protection Agency, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, Dec. 1970. 379 p.

38. Arthur D. Little, Inc. Inorganic chemical pollution of freshwater. Water Quality Criteria Data Book. v.2. U.S. Environmental Protection Agency, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, July 1971. 280 p.

39. U.S. Bureau of the Census. 1967 Census of manufacturers. v.1. Summary and subject statistics. Washington, U.S. Government Printing Office, Jan. 1971

40. 1972 Directory of chemical producers. Menlo Park, Calif., Stanford Research Institute. [Published quarterly.]

*41. Personal communication. Mr. Brower, Explosive Engineering Corporation, Ontario, Calif., Sept. 1972.

*42. Personal communication. Mrs. Brandon, American Type Culture Association, 1969. Based on 21,000 shipments of 1-3 milliliter quantities and appropriate growth estimates.

*43. Personal communication. Mr. Herman Nack, Battelle Memorial Institute, Columbus Laboratories, Feb. 1973.

44. Report on technical evaluation studies to develop pollution abatement facilities at Pine Bluff Arsenal, Pine Bluff, Arkansas. Report prepared for U.S. Department of the Army, Fort Worth District. Brisbane, Calif., Envirotech Systems, Inc., Dec. 1971.

*45. Personal communication. Joint Committee on Disposal Assured, to Dr. Greenfield, U.S. Environmental Protection Agency, Nov. 21, 1972.

46. Ferguson, J. F., and J. Gavis. A review of the arsenic cycle in natural waters. Water Research, 6(11):1,259-1,274, Nov. 1972.

*47. Personal communication. Analytical Quality Control Laboratory, National Environmental Research Center, Cincinnati, Feb. 1971.

*48. Personal communication. Mr. Herman Nack, Review of waste disposal practices. Chem-Trol Pollution Services, Inc., Buffalo, N.Y. Oct. 19, 1972.

49. Schink, C. A. Plating wastes: a simplified approach to treatment. Plating, 55(12):1,302-1,305, Dec. 1968.

50. Snowden, F. C. Metal-finishing wastes can become potable effluent. Water and Sewage Works, 116(5):IW9-IW11, May 1969.

51. Stone, E. H. F. Treatment of non-ferrous metal process waste at Kynoch Works, Birmingham, England. In Proceedings; 22nd Industrial Waste Conference, Purdue University, May 2-4, 1967. Engineering Extension Series No. 129. p.848-865.

52. Skripach, T., V. Kagan, M. Romanov, L. Kamen, and A. Semina. Removal of fluorine and arsenic from the wastewater of the rare-earth industry. In Advances in Water Pollution Research; Proceedings, 5th International Conference, San Francisco and Hawaii, 1970. v.2. New York, Pergamon Press, 1971. p.111-34/1-34/7.

*53. Fisco, R. A. Plating and industrial waste treatment at the expanded plant of Fisher Body, Elyria, Ohio. [Purdue Industrial Waste Conference, 1967. p.306-313.]

54. Nemerow, N. L. Liquid waste of industry: theories, practices, and treatment. Reading, Mass., Addison-Wesley Publishing Company, 1971. p.83-102.

55. Emmett, R. C. Liquid-solids separation in waste treatment in the mining industry; conventional techniques and new concepts. Preprint 71-B-346. Presented at Fall Meeting, Society of Mining Engineers, Seattle, Wash., Sept. 22-24, 1971. 10 p.

56. Lund, H. F., ed. Industrial pollution control handbook. New York, McGraw-Hill Book Company, 1971. p.6/17-6/18, 24/7-24/9.

57. Burns and Roe, Inc. Process design manual for suspended solids removal. Washington, U.S. Environmental Protection Agency, Technology Transfer, Oct. 1971. [107 p.]

58. Culp, R. L., and G. L. Culp. Advanced wastewater treatment. New York, Van Nostrand Reinhold Company, 1971. p.17-50, 87-132.

59. Weber, W. J., Jr. Physiochemical processes for water quality control. New York, Wiley-Interscience Publishers, 1972. p.61-198.

60. A new German method of destroying cyanide wastes. Chemical Week, 111(25):32, Dec. 20, 1972.

61. Allen, R. The disposal of waste materials in the electroplating industry. In Society of Chemical Industry, Disposal of Industrial Waste Materials; Papers read at the Conference at Sheffield University, Apr. 17-19, 1956. New York, MacMillan Company, 1957. p.81-88.

62. Battelle Memorial Institute. A state-of-the-art review of metal finishing waste treatment. U.S. Federal Water Quality Administration, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, Nov. 1968. [81 p.]

63. New chemical destroys cyanide in zinc plate rinses. Products Finishing, 35(3):130-133, Dec. 1970.

64. Easton, J. K. Electrolytic decomposition of concentrated cyanide plating wastes. Water Pollution Control Federation Journal, 39(10):1,621-1,625, Oct. 1967.

65. Howe, R. H. L. Recent advance in cyanide waste reduction practice. In Proceedings; 18th Industrial Waste Conference, Purdue University, Apr. 30-May 2, 1963. Engineering Extension Series No. 115. p.690-705.

66. Battelle Memorial Institute. An investigation of techniques for removal of chromium from electroplating wastes. U.S. Environmental Protection Agency, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, Mar. 1971. 91 p.

67. CN and CR: packaged destruction. Products Finishing, 35(1):101-105, Oct. 1970.

68. Plating waste treatment at Proctor-Silex. Products Finishing, 35(4):43-49, Jan. 1971.

69. Haviland, J. M. Effluent treatment: cutting cost of compliance. Products Finishing, 35(5):46-54, Feb. 1971.

70. D'Orazio, A. J. Pretreatment of cyanide and chromium wastes plus treatment of oily wastes. In Proceedings; 14th Industrial Wastes Conference, Purdue University, May 5-7, 1959. Engineering Extension Series 104. p.7-15.

71. Grieves, R. B., and D. Bhattacharyya. Precipitate flotation of complexed cyanide. In Proceedings; 24th Industrial Waste Conference, Purdue University, May 6-8, 1969. Engineering Extension Series 135. p.989-997.

72. Silman, H. Treatment of rinse water from electrochemical processes. Metal Finishing, 69(6):62-66, June 1971.

73. Schreur, N. The Lancy Integrated System for treatment of cyanide and chromium wastes in electroplating plants. In Proceedings; 22nd Industrial Waste Conference, Purdue University, May 2-4, 1967. Engineering Extension Series No. 129. p.310-316.

74. Shreve, R. N. Chemical process industries. 3d ed. New York, McGraw-Hill Book Company, 1967. p.73.

75. Gurnham, C. F., *ed.* Industrial wastewater control. New York, Academic Press, 1965. p.225-226.

76. Burleson, N. K., W. W. Eckenfelder, Jr., and J. F. Malina, Jr. Tertiary treatment of secondary industrial effluents by activated carbon. *In* Proceedings; 23rd Industrial Waste Conference, Purdue University, May 7-9, 1968. Engineering Extension Series 132. p.474-483.

77. Henshaw, T. B. Adsorption/filtration plant cuts phenols from effluent. *Chemical Engineering,* 78(12):47-49, May 31, 1971.

78. Fox, R. D., R. T. Keller, C. J. Pinamount, and J. L. Steverson. Purification of waste brine by carbon adsorption with emphasis on wastewater reuse. *In* Proceedings; 25th Industrial Waste Conference, Purdue University, May 5-7, 1970. Engineering Extension Series 137. p.322-330.

*79. Van Stone, G. R. A solution to industrial wastewater treatment: granular activated carbon. *In* 31st Annual Meeting, International Water Conference, Pittsburgh, Oct. 27-29, 1973. p.45-48. Engineers' Society of Western Pennsylvania.

80. Hassler, J. W. Activated carbon. rev. ed. New York, Chemical Publishing Company, Inc., 1963. 397 p.

81. Gould, M., and J. Taylor. Makeshift granular carbon system resolves phenol lagoon pollution threat. Chemical Engineering Progress Symposium Series No. 97. New York, American Institute of Chemical Engineers, 1969. p.196-199.

*82. Weber, W. J., Jr. Direct physicochemical treatment. Process Design in Water Quality Engineering: New Concepts and Developments, Symposium sponsored by Vanderbilt University, Nov. 1-5, 1971.

83. Kincannon, D. F., and A. F. Gaudy, Jr. Some effects of high salt concentrations on activated sludge. *In* Proceedings; 20th Industrial Waste Conference, Purdue University, May 4-6, 1965. Engineering Extension Series No. 118. p.316-328.

84. Barnhart, E. L. Aerated lagoons. *In* W. W. Eckenfelder, *ed.* Process Design in Water Quality Engineering: New Concepts and Developments, Symposium, Nashville, Tenn., Nov. 1-5, 1971. Vanderbilt University. p.93-106.

85. Dean, R. B. Ultimate disposal of waste water: a philosophical view. Chemical Engineering Progress Symposium Series No. 97. New York, American Institute of Chemical Engineers, 1969. p.1-4.

86. Gunderloy, F. C., Jr., et al. Dilute solution reactions of nitrate ion as applied to water reclamation. Report TWRC-1. Washington, U.S. Department of the Interior, Federal Water Pollution Control Administration, Oct. 1968. 67 p.

87. Barthauer, G. L., Z. V. Kosowski, and J. P. Ramsey. Control of mine drainage from coal mine mineral wastes: phase 1. Hydrology and related experiments. U.S. Environmental Protection Agency, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, Aug. 1971. 148 p.

88. Blanco, R. E., H. W. Godbee, and E. J. Fredrick. Incorporating industrial wastes in insoluble media. Chemical Engineering Progress, 66(2):51-56, Feb. 1970.

89. Bear, J., D. Zaslavsky, and S. Irmay, eds. Physical principles of water percolation and seepage. New York, United Nations Educational, Scientific, and Cultural Organization, 1968. 465 p.

*90. Personal communication. J. P. Flynn, Dow Chemical Company, to B. W. Mercer, Battelle Northwest Laboratories.

*91. Effluent limitation guidance for the refuse act program--Metal Finishing Industry, 1972.

92. Powell, H. E., L. L. Smith, and A. A. Cochran. Recovery of phosphates and metals from phosphate sludge by solvent extraction. U.S. Bureau of Mines Report of Investigations 7662. Washington, U.S. Department of the Interior, [1972]. 12 p.

93. Waters, R. F., H. E. Powell, and A. A. Cochran. Recovery of metals and phosphates from waste phosphate sludge. Metal Finishing, 69(8):39-42, Aug. 1971.

94. New rules dull solvents' sheen. Chemical Week, 111(20):36, Nov. 15, 1972.

*95. U.S. Bureau of the Census. Current industrial reports. Sales of lubricating and industrial oils and greases. 1965.

96. National Oil Recovery Corporation. Conversion of crankcase waste oil into useful products. U.S. Environmental Protection Agency, Water Pollution Control Research Series. Washington, U.S. Government Printing Office, Mar. 1971. 87 p.

97. Final Report of the API Task Force on Used Oil Disposal. Publication No. 4036. New York, American Petroleum Institute, 1970. 44 p.

*98. Personal communication. J. S. Talbot, Dow Chemical Company, Houston, Tex., to J. P. Flynn, Dow Chemical Company, Midland, Mich., Jan. 22, 1973.

99. Code of Federal Regulations. Title 10. Energy. Part 20. Standards for protection against radiation. Washington, U.S. Government Printing Office, 1974. p.154-180.

100. Rodgers, L. Discussion of proposed amendments to AEC regulations on radioactive effluents from light water cooled nuclear power reactors. Presented at 2d Conference on Radiation and Man's Environment, U.S. Atomic Energy Commission, Buck Hill Falls, Pa., Apr. 20, 1970. 11 p. [Distributed by National Technical Information Service, Springfield, Va., as CONF-700408-4.]

*101. ICAE Hearings; radiation protection criteria and standards: their bases and uses. May-June 1960.

102. Nuclear legislation; analytical study. Paris, Organisation for Economic Co-operation and Development, 1972. 494 p.

103. Maximum permissible body burdens and maximum permissible concentrations of radionuclides in air and in water for occupational exposure. National Bureau of Standards Handbook 69. Washington, U.S. Government Printing Office, 1959. 95 p.

104. Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water. National Bureau of Standards Handbook 52. Washington, U.S. Government Printing Office, 1953. 45 p.

105. Code of Federal Regulations; cumulative pocket supplement. Title 10. Atomic energy. Part 20. Standards for protection against radiation. Washington, U.S. Government Printing Office, Jan. 1, 1958. p.50-61.

106. Atomic Energy Commission. Licensing of production and utilization facilities. Federal Register, 36(111):11,113-11,117, June 9, 1971.

*107. A scientific committee (NAS-NRC) supports the Gofman-Tamplin theories. Nucleonics Week, p.5-6, Nov. 30, 1972.

108. Lenneman, W. L. United States Atomic Energy Commission interim radioactive waste burial program. In Joint IAEA/ENEA Symposium on the Disposal of Radioactive Wastes into the Ground, Vienna, Austria. Vienna, International Atomic Energy Agency, 1967. p.261-300.

109. Peckham, A. E., and W. G. Belter. Considerations for selection and operation of radioactive waste burial sites. In J. M. Morgan, Jr., D. K. Jamison, and J. D. Stevenson, eds. Ground Disposal of Radioactive Wastes; Second Conference Proceedings, Chalk River, Canada, Sept. 26-29, 1961. U.S. Atomic Energy Commission Report TID-7628. Washington, Mar. 1962. p.460-461.

110. Richardson, R. M. Northeastern burial ground studies. In J. M. Morgan, Jr., D. K. Jamison, and J. D. Stevenson, eds. Ground Disposal of Radioactive Wastes; Second Conference Proceedings, Chalk River, Canada, Sept. 26-29, 1961. U.S. Atomic Energy Commission Report TID-7628. Washington, Mar. 1962. p.460-461.

*111. Division of Materials Licensing. Licensing requirements for establishment of a land burial facility for burial of radioactive wastes. U.S. Atomic Energy Commission.

112. Morton, R. J. Land burial of solid radioactive wastes: study of commercial operations and facilities. Washington, U.S. Atomic Energy Commission, 1968. 133 p. [Distributed by National Technical Information Services, Springfield, Va., as WASH-1143.]

113. Radioactive materials and other miscellaneous amendments. Federal Register, 33(194):14,918-14,936, Oct. 4, 1968.

114. Rogers, L. R. Management of waste from the use of radioisotopes. In Disposal of Radioactive Wastes; Conference Proceedings, Monaco, Nov. 16-21, 1959. v.1. Vienna, International Atomic Energy Agency, 1960. p.51.

115. U.S. Atomic Energy Commission. The nuclear industry; 1971. Report WASH 1174-71. Washington, U.S. Government Printing Office, 1971. p.153-157, 179-185.

116. Radiation control in the State of New York. Albany, New York Office of Atomic Development, Atomic Energy Coordinating Council, Committee on Licensing, 1963. 171 p.

*117. New York Department of Health Regulations. chap.16.

*118. New York Department of Labor. Rule #38.

119. Kentucky State Department of Health radiological health "RH" regulations. Frankfort, Oct. 1968.

120. Regulations for radiation control. Olympia, Washington State Department of Health, Dec. 1966. 114 p.

*121. Program for the regulation of use of ionizing radiation. Washington State Department of Health, 1966.

*122. Rules and regulations for radiation protection. Title 402, WAC. State of Washington.

123. Water pollution control laws. rev. ed. Olympia, State of Washington, Department of Ecology, Sept. 1971. [28 p.]

*124. Surface and ground water codes. chap.90.03-90.44, RCW. State of Washington.

*125. Solid waste management. chap.70.95, TCW.

*126. State of Connecticut Public Act #46, 1955.

*127. State of Florida Senate Bill #34, 1955.

128. An Act to create the Atomic Power Investigating Commission. Illinois Senate Bill #577. Springfield, 1955.

129. An act to coordinate development and regulatory activity relating to the peaceful uses of atomic energy. New Hampshire Session Laws, chap.281. Concord, 1955.

*130. Radiation Protection Regulations. State of Oklahoma, 1969.

*131. Regulations on radiation exposure. Texas State Department of Health.

*132. Personal communication. G. Jansen, Battelle-Northwest, to D. E. Larson, Atlantic Richfield Hanford Company, July 26, 1972.

133. Environmental survey of the nuclear fuel cycle. Washington, Directorate of Licensing, U.S. Atomic Energy Commission, Nov. 1972. 339 p. [Distributed by National Technical Information Service, Springfield, Va., as WASH-1237.]

*134. Nichols, J. P., et al. Projection of fuel reprocessing requirements and high-level solidified wastes from the U.S. nuclear industry. Report ORNL-TM-3965. U.S. Atomic Energy Commission, Sept. 1972. [Draft.]

135. Soldat, J. K. Modeling of environmental pathways and radiation doses from nuclear facilities. Richland, Wash., Battelle Northwest Laboratories, Oct. 1971. 33 p. [Distributed by National Technical Information Service, Springfield, Va., as BNWL-SA-3939.]

136. Claiborne, H. C. Neutron-induced transmutation of high-level radioactive waste. Oak Ridge National Laboratory, Tenn., Dec. 1972. p.35-39, 79-84. [Distributed by National Technical Information Service, Springfield, Va., as ORNL-TM-3964.]

*137. Data for preliminary demonstration phase of an environmental quality information and planning system. Report BNWL-B-141. Battelle-Northwest Laboratories, Dec. 1971.

*138. Rubi, J. H. Evolving U.S. policies in radioactive waste management. Presented at the AIF/ANL International Conference, Washington, Nov. 15, 1972. p.1.

139. Schneider, K. J. Radioactive waste from nuclear power in the USA. Paper EQC 30. In AIME Environmental Quality Conference, Washington, June 7-9, 1971. New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. p.103-118.

*140. Data for preliminary demonstration phase of the environmental quality information and planning systems (EQUIPS). Report BNWL-B-141. Battelle-Northwest Laboratories, Dec. 1971.

141. Curl, R., comp. List of AEC radioisotope customers with summary of radioisotope shipments, FY 1971. Oak Ridge, Tenn., Oak Ridge National Laboratory, Feb. 1972. 34 p. [Distributed by National Technical Information Service, Springfield, Va., as ORNL-IIC-38.]

*142. Personal communication. B. I. Griffin, and C. A. Rohrmann, Battelle-Northwest Laboratories, to J. D. Kaser, Battelle-Northwest, Oct. 1972.

143. Basic factors for the treatment and disposal of radioactive wastes. STI/PUB/170. Vienna, International Atomic Energy Agency, 1967. p.19.

144. U.S. Atomic Energy Commission, Division of Industrial Participation. The nuclear industry--1971. Report WASH-1174-71. Washington, U.S. Government Printing Office, 1971. p.5.

145. Booz, Allen Applied Research, Inc. A study of hazardous waste materials, hazardous effects and disposal methods. v.3. U.S. Environmental Protection Agency Contract No. 68-03-0032. [Bethesda, Md.], June 30, 1972.

*146. Godbee, H. W., and J. P. Nichols. Sources of transuranium solid waste and their influence on the proposed national radioactivity waste respository. Report ORNL-TM-3277. [Washington], U.S. Atomic Energy Commission, Jan. 1971. [Restricted distribution.]

*147. Personal communication. A. F. Perge, Deputy Director, Division of Waste Management and Transportation, U.S. Atomic Energy Commission, to W. H. Swift, Battelle-Northwest, Dec. 1, 1972.

*148. Personal communication, A. F. Perge to W. H. Swift.

*149. Burial Grounds. NMIS Report I-213, June 30, 1972.

*150. Hanford radioactive waste management plans. Report PWM-530. U.S. Atomic Energy Commission, Aug. 1972.

*151. Management of radioactive wastes at the Savannah River Plant. Presented to the Committee on Radioactive Waste Management, National Academy of Sciences, Jan. 20-21, 1969.

*152. Personal communication, A. F. Perge to W. H. Swift.

*153. Savannah river plant radioactive waste management plan. Report DPST-72-383. U.S. Atomic Energy Commission, Sept. 1972.

*154. Personal communication. F. P. Baranowski to M. B. Biles, July 8, 1971. Draft staff paper regarding dispostion of licensee generated plutonium-contaminated waste materials.

*155. Idaho operations office waste management plan. Report IDO-10050. U.S. Atomic Energy Commission, Aug. 1972. p.IX36-IX40.

*156. U.S. Atomic Energy Commission Report CF 72-9-1. Oak Ridge National Laboratory, Sept. 1972, p.56.

*157. Radioactive waste management plans. ORNL Report UCC-ND-215. U.S. Atomic Energy Commission, Aug. 15, 1972.

*158. Personal communication, A. F. Perge to W. H. Swift.

*159. Personal communication, A. F. Perge to W. H. Swift.

160. Morgan, J. M., Jr., D. K. Jamison, and J. D. Stevenson, eds. Ground Disposal of Radioactive Wastes; Second Conference Proceedings, Chalk River, Canada, Sept. 26-29, 1961. U.S. Atomic Energy Commission Report TID-7628. Washington, Mar. 1962. 635 p.

161. Purtymun, W. D. Plutonium in stream channel alluvium in the Los Alamos Area, New Mexico. Los Alamos Scientific Laboratories, Nov. 1970. 7 p. [Distributed by National Technical Information Service, Springfield, Va., as LA-4561.]

*162. Personal communication, A. F. Perge to W. H. Swift.

*163. Personal communication. D. E. Larson, Atlantic Richfield Hanford Company, to G. Janson, Battelle-Northwest, July 1972.

*164. Warren, J. H., C. M. Unruh, P. W. Smith, A. E. Smith and R. E. Isaacson. Management of high-level radioactive wastes at the Hanford site. U.S. Atomic Energy Commission, Sept. 1972.

*165. Jacobs, M. C., and J. D. Anderson. Radioactivity in gaseous waste discharged from the separation facilities during 1971. Report ARH-2353, pt.1. U.S. Atomic Energy Commission, Apr. 25, 1972.

*166. Jacobs, M. C., and J. D. Anderson. Summary of radioactive solid waste burials in the 200-areas during 1971. Report ARH-2353, pt.2. U.S. Atomic Energy Commission, Feb. 8, 1972.

*167. Jacobs, M. C., and J. D. Anderson. Radioactive liquid wastes discharged to ground in the 200-areas during 1971. Report ARH-2352. U.S. Atomic Energy Commission, Mar. 13, 1972.

*168. Szulinski, M. J. Preliminary problem definition decommissioning the Hanford site. Report ARH-2164. U.S. Atomic Energy Commission, Apr. 1972.

*169. Larson, D. E. High-level liquid radioactive waste management plan. Report ARH-2400. U.S. Atomic Energy Commission, Apr. 1972.

*170. Larson, High-level liquid radioactive waste, Apr. 1972.

*171. Miles, M. E., J. J. Mangeno, and R. D. Burke. Environmental monitoring and disposal of radioactive wastes from U.S. naval nuclear-powered ships and their support facilities. Report NT-71-1. U.S. Department of the Navy, Feb. 1971.

172. Code of Federal Regulations. Title 49. Transportation. Parts 170-189, subchapter A. Hazardous Materials Regulations Board. Washington, U.S. Government Printing Office, 1973. p.5-787.

173. Code of Federal Regulations. Title 10. Energy. Part 71. Packaging of radioactive material for transport and transportation of radioactive material under certain conditions. Washington, U.S. Government Printing Office, 1974. p.362-378.

174. Code of Federal Regulations. Title 14. Aeronautics and space. Part 103. Transportation of dangerous articles and magnetized materials. Washington, U.S. Government Printing Office, 1974. P.182-188.

175. Code of Federal Regulations. Title 46. Shipping. Part 146. Transportation or storage of explosives or other dangerous articles or substances and combustible liquids on board vessels. Washington, U.S. Government Printing Office, 1972. p.3-893.

176. Code of Federal Regulations. Title 49. Transportation. Part 397. Transportation of hazardous materials; driving and parking rules. Washington, U.S. Government Printing Office, 1973. p.324-327.

177. Code of Federal Regulations. Title 39. Postal service. Part 124. Matter mailable under special rules. Washington, U.S. Government Printing Office, 1973. p.95-113. [Originally classified as regulations 14-15; revised in 1968.]

178. Conlon, F. B., and G. L. Pettigrew. Summary of Federal regulations for packaging and transportation of radioactive materials. U.S. Department of Health, Education, and Welfare, Radiological Health Bureau, BRH/DMRE 71-1. Washington, U.S. Government Printing Office, Feb. 1971. 37 p.

179. Regulations for the safe transport of radioactive materials. 1967 ed. Safety Series No. 6. Vienna, International Atomic Energy Agency, 1967. 117 p. [Distributed by UNIPUB, Inc., New York, as STI/PUB/148.]

180. Barker, R. F. How changes in the IAEA regulations may affect 10 CFR Part 71. *In* Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.1. p.62-74. [Distributed by National Technical Information Service, Springfield, Va., as CONF-710801.]

181. Gibson, R., *ed.* The safe transport of radioactive materials. Oxford, England, Pergamon Press, 1966. 290 p.

182. McCluggage, W. C. The AEC accident record and recent changes in AEC manual chapter 0529. *In* Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.3. p.108-129. [Distributed by National Technical Information Service, Springfield, Va., as BNWL-SA-3906.]

183. Loy, H. L., and D. C. Saxena. Processing and packaging wastes from BWR's. *In* Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.1. p.478-489. [Distributed by National Technical Information Service, Springfield, Va., as CONF-710801.]

*184. Directory of shipping containers for radioactive materials. U.S. Atomic Energy Commission, Division of Waste Management and Transportation.

185. Brobst, W. A. Transportation of radioactive waste: worth its salt. In Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.1. p.356-379. [Distributed by National Technical Information Service, Springfield, Va., as CONF-710801.]

186. Gablin, K. Design considerations for high volume IAEA type B protective overpack shipping containers in use with current transportation systems. In Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.1. p.490-502. [Distributed by National Technical Information Service, Springfield, Va., as CONF-710801.]

187. Bechthold, W., J. Heil, M. C. Schuchardt, and R. Wolf. Shielded transport containers for intermediate and high level radioactive wastes. In Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.1. p.195-208. [Distributed by National Technical Information Service, Springfield, Va., as CONF-710801.]

*188. Szulinski, M. J., et al. Waste management special studies; progress report 5. Report ARH-2437E. Atlantic Richfield Hanford Company, Nov. 1972. p.2-1.

189. U.S. Atomic Energy Commission. The nuclear industry; 1971. Report WASH 1174-71. Washington, U.S. Government Printing Office, 1971. 199 p.

190. Handling collisions and derailments involving explosives, gasoline, and other dangerous articles. Pamphlet No. 22. Washington, Association of American Railroads, Bureau of Explosives, Sept. 1969.

191. U.S. Atomic Energy Commission. Radiological emergency procedures for the non-specialist. Washington, U.S. Government Printing Office, Jan. 1969. 35 p.

192. Ayres, J. A., ed. Decontamination of nuclear reactors and equipment. New York, Ronald Press, 1970. 825 p.

193. Code of Federal Regulations. Title 10. Energy. Part 30. Rules of general applicability to licensing of byproduct material. Washington, U.S. Government Printing Office, 1974. p.189-203.

194. Code of Federal Regulations. Title 10. Energy. Part 70. Special nuclear material. Washington, U.S. Government Printing Office, 1974. p.342-362.

195. Fairey, J. Development of documentation for the transport of radioactive materials. In Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.3. p.182-192. [Distributed by National Technical Information Service, Springfield, Va., as BNWL-SA-3906.]

196. Code of Federal Regulations. Title 10. Energy. Part 73. Physical protection of plants and materials. Washington, U.S. Government Printing Office, 1974. p.378-389.

*197. Physical protection of unclassified special nuclear material. Immediate Action Directive No. 2405-19. U.S. Atomic Energy Commission, Feb. 14, 1973.

198. U.S. Atomic Energy Commission. Plan for the management of AEC-generated radioactive wastes. Report WASH-1202. Washington, U.S. Government Printing Office, Jan. 1972. 40 p.

199. Godbee, H. W. Spontaneous combustion, oxidation, and pyrolysis of combustible solid wastes containing transuranium elements in combustible and noncombustible containers. Oak Ridge, Tenn., Oak Ridge National Laboratory, May 1972. p.3. [Distributed by National Technical Information Service, Springfield, Va., as ORNL-4768.]

200. Lerch, R. E., C. R. Cooley, and R. C. Smith. Treatment of alpha-contaminated solid waste by acid digestion. Transactions of the American Nuclear Society, 15(2):665-666, Nov. 1972.

*201. Code of Federal Regulations. Title 20. Part 303.

*202. Kentucky radioactive waste disposal site inventory report. Prepared for the U.S. Environmental Protection Agency under requisition No. 62-TIRB-TAD-054, 1972.

*203. Code of Federal Regulations. Title 20. Parts 103-106.

204. Code of Federal Regulations. Title 10. Energy. Part 50, appendix f. Policy relating to the siting of fuel reprocessing plants and related waste management facilities. Washington, U.S. Government Printing Office, 1974. p.310-311.

205. Code of Federal Regulations. Title 49. Transportation. Part 173. Shippers. sec.173.393 and 173.398. Washington, U.S. Government Printing Office, 1973. p.265, 274.

*206 Management and ultimate disposal of high-level radioactive wastes from the commercial nuclear fuel cycle; draft report. Energy Policy Committee, Division of Technology Assessment, Office of Radiation Programs, U.S. Environmental Protection Agency, Oct. 1972.

207. Wolkenhauer, W. C. Controlled thermonuclear reactor as a fission product burner. *In* Pacific Northwest Laboratory annual report on controlled thermonuclear reactor technology. Richland, Wash., Battelle Pacific Northwest Laboratories, Nov. 1972. p.33-52. [Distributed by National Technical Information Service, Springfield, Va., as BNWL-1685.]

*208. Szulinski, M. J., *et al.* Waste management special studies progress report no. 4. U.S. Atomic Energy Commission Report ARH-2437D. Atlantic Richfield Hanford Company, Sept. 1972. p.4-3.

*209. Szulinski, M. J., *et al.* Waste management special studies progress report no. 3. U.S. Atomic Energy Commission Report ARH-2437C. Atlantic Richfield Hanford Company, July 1972.

*210. Kennedy, R. A. High-level engineered storage facility, concept selection. U.S. Atomic Energy Commission Report ARH-2598. Atlantic Richfield Hanford Company, Oct. 1972. p.3.

211. Perona, J. J., and J. O. Blomeke. A parametric study of shipping casks for solid radioactive wastes. Oak Ridge, Tenn., Oak Ridge National Laboratory, Feb. 1972. 42 p. [Distributed by National Technical Information Service, Springfield, Va., as ORNL-TM-3651.]

212. Code of Federal Regulations. Title 49. Transportation. Part 173. Shippers. sec.173.389-173.398. Washington, U.S. Government Printing Office, 1973. p.258-274.

*213. Szulinski, Waste management special studies, p.6-1, 6-5.

*214. Szulinski, Waste management special studies, p.6-3.

*215. Szulinski, Waste management special studies, p.6-4.

216. Oak Ridge National Laboratory. Reactor fuel cycle costs for nuclear power evaluation. Report WASH-1099. Washington, U.S. Government Printing Office, Dec. 1971. 260 p.

*217. Kennedy, R. A. Alpha engineered storage facility, close out report. Report ARH-2447-RD. U.S. Atomic Energy Commission, June 1972.

*218. Fowler, E. B. Transuranic waste repository studies. [Informal] Report LA5127-MS. v.1. U.S. Atomic Energy Commission, Dec. 1972.

219. U.S. Atomic Energy Commission. The nuclear industry; 1971. Report WASH 1174-71. Washington, U.S. Government Printing Office, 1971. 199 p.

220. Lenneman, W. L., *ed.* Incineration of radioactive solid wastes. Washington, U.S. Atomic Energy Commission, Aug. 1970. 151 p. [Distributed by National Technical Information Service, Springfield, Va., as WASH-1168.]

*221. Kuhn, K., W. Diefenbacher, H. Drause and H. Schmidt. Disposal of solidified high level wastes in the Asse salt mine. Paper No. 35. *In* OECD-IAEA Symposium on the Management of Radioactive Wastes from Fuel Reprocessing, Paris, Nov. 27-Dec. 1, 1972. Office of Economic Cooperation and Development.

222. Blythe, H. J., *ed.* Proceedings; First International Symposium on the Decontamination of Nuclear Installations, Harwell, England, May 4-6, 1966. Cambridge University Press, 1967. 348 p.

223. Ayres, J. A. Equipment decontamination with special attention to solid waste treatment: survey report. Richland, Wash., Battelle-Northwest Laboratories, June 1971. 91 p. [Distributed by National Technical Information Service, Springfield, Va., as BNWL-B-90.]

224. Compaction of radioactive solid waste. Washington, U.S. Atomic Energy Commission, June 1970. 41 p. [Distributed by National Technical Information Service, Springfield, Va., as WASH-1167.]

*225. Hammond, V. L., *et al.* Energy from solid wastes by pyrolysis-incineration. Battelle-Northwest Report BNWL-SA-4471. Presented at Annual Meeting, Air Pollution Control Association, Pacific Northwest International Section, Eugene, Oreg., Nov. 1972.

*226. Kulichenko, V. V., *et al.* Potentials of the method of bitumenization for treating high-level wastes. *In* OECD-IAEA Symposium on Management of Radioactive Wastes from Fuel Reprocessing, Paris, Nov. 27-Dec. 1, 1972. Office of Economic Cooperation and Development.

227. Rutland, L. Economics, compositions, and process equipment for radioactive waste solidification. *In* Proceedings; Third International Symposium on Packaging and Transportation of Radioactive Materials, Richland, Wash., Aug. 16-20, 1971. v.2. p.785-791. [Distributed by National Technical Information Service, Springfield, Va., as CONF-710801.]

228. National atlas of the United States of America. Washington, U.S. Geological Survey, 1970. 417 p.

229. Rima, D. R., E. B. Chase, and B. M. Myers. Subsurface waste disposal by means of wells; selective annotated bibliography. U.S. Geological Survey Water Supply Paper 2020. Washington, U.S. Government Printing Office, 1971. 305 p.

*230. Environmental geology and hydrology, Madison County, Alabama. Atlas Series 1, Geological Survey of Alabama, 1971.

*231. Physical environment of Saskatoon, Canada. Publication 11378. Ottawa, National Research Council of Canada, 1970.

232. Krynine, D. P., and W. R. Judd. Principles of engineering geology and geotechnics. New York, McGraw-Hill Book Company, 1957. 730 p.

233. Olson, R. A., and M. M. Wallace, eds. Geologic Hazards and Public Problems; Conference Proceedings, Office of Emergency Preparedness, Santa Rosa, Calif., May 27-28, 1969. Washington, U.S. Government Printing Office. 334 p.

234. Landes, K. K. Petroleum geology of the United States. New York, Wiley-Interscience, 1970. 571 p.

235. Proceedings; Annual Engineering Geology and Soils Engineering Symposium, Moscow, Idaho, [1968-1972]. v.6-10. Idaho Department of Highways, University of Idaho, and Idaho State University.

236. Fennemann, N. M. Physiography of the Eastern United States. New York, McGraw-Hill Book Company, 1938. 714 p.

237. Arndt, B. M. Geology for planning at Langdon, North Dakota. Report of Investigation No. 50. North Dakota Geological Survey, 1972. 16 p.

238. Colton, G. W. Geologic summary of the Appalachian Basin, with reference to the subsurface disposal of radioactive waste solutions. Washington, U.S. Geological Survey, June 1961. 219 p. [Distributed by National Technical Information Service, Springfield, Va., as TEI-791.]

239. DeWitt, W., Jr. Geology of the Michigan basin with reference to subsurface disposal of radioactive wastes. Report TEI-771, prepared by the U.S. Atomic Energy Commission. Washington, U.S. Geological Survey, 1960.

*240. Sandberg, C. A. Geology of the Williston Basin, North Dakota, Montana, and South Dakota, with reference to subsurface disposal of radioactive wastes. Report TEI-801, prepared by the U.S. Atomic Energy Commission. Washington, U.S. Geological Survey, June 1962.

241. Beikman, H. M. Geology of the Powder River Basin, Wyoming and Montana, with reference to subsurface disposal of radioactive wastes. Washington, U.S. Geological Survey, Feb. 1962. 94 p. [Distributed by National Technical Information Service, Springfield, Va., as TEI-823.]

242. Love, J. D., and L. Hoover. A summary of the geology of sedimentary basins of the United States, with reference to the disposal of radioactive wastes. Report TEI-768, prepared by the U.S. Atomic Energy Commission. Washington, U.S. Geological Survey, 1960.

243. Repenning, C. A. Geologic summary of the Central Valley of California, with reference to disposal of liquid radioactive waste. Report TEI-769, prepared by U.S. Atomic Energy Commission. Washington, U.S. Geological Survey, 1960.

*244. Kiel, G. R. Engineered storage facility site recommendation. Report ARH-2674. Richland, Atlantic Richfield Hanford Company, Dec. 1962.

245. LeGrand, H. E. Geology and ground-water hydrology of the Atlantic and Gulf coastal plain as related to disposal of radioactive wastes. Washington, U.S. Geological Survey, Jan. 1962. 218 p. [Distributed by National Technical Information Service, Springfield, Va., as TEI-805.]

246. MacLachlan, M. E. The Anadarko Basin (of parts of Oklahoma, Texas, Kansas, and Colorado). Washington, U.S. Geological Survey, Mar. 1964. 99 p. [Distributed by National Technical Information Service, Springfield, Va., as TEI-831.]

*247. Destruction and disposal of inactivated antcrop biological agent at Fort Detrick, Maryland. U.S. Army Munitions Command, July 17, 1972.

*248. Warner, D. L. Survey of industrial waste injection wells; final technical report to U.S. Geological Survey. Rolla, Department of Geological Engineering, University of Missouri, June 1972.

*249. Sanitary disposal projects. Title XXV. Iowa City, Iowa State Department of Health, 1971.

250. Hughes, G. M., and K. Cartwright. Scientific and administrative criteria for shallow waste disposal. Civil Engineering-ASCE, 42(3):70-73, Mar. 1972.

251. Bailey, B. L., and A. M. Malatino. Contamination of ground water in a limestone aquifer in the Stevenson Area, Alabama. Circular 76. Geological Survey of Alabama, 1971. 15 p.

252. Hughes, G. M., R. A. Landon, and R. N. Farvolden. Hydrogeology of solid waste disposal sites in northeastern Illinois; a final report on a solid waste demonstration grant project. Washington, U.S. Government Printing Office, 1971. 154 p.

253. Subsurface water pollution; a selective annotated bibliography. Washington, U.S. Environmental Protection Agency, 1972. 3 v.

254. Ballentine, R. K., S. R. Reznek, and C. W. Hall. Subsurface pollution problems in the United States. U.S. Environmental Protection Agency, Water Programs Office. Washington, U.S. Government Printing Office, May 1972. 24 p.

*255. Water resources investigations in Colorado--1968. Conducted by the United States Geological Survey Water Resources Division in cooperation with the Colorado Water Conservation Board. Washington, 1968.

*256. Manual. Real estate management. chap.5301, appendix 5301 and annexes A, B, C, D & E. Washington, U.S. Atomic Energy Commission, June 17, 1960.

*257. Site selections. chap.6202. Washington, U.S. Atomic Energy Commission, June 16, 1972.

*258. Manual. Site development planning. chap.6203 and appendix 6203. Washington, U.S. Atomic Energy Commission, June 16, 1972.

259. Walker, W. H. Illinois ground water pollution. *Journal of the American Water Works Association,* 61(1):31-40, Jan. 1969.

*260. Van Everdingen, R. O., and R. A. Freeze. Subsurface disposal of waste in Canada; injection of liquid industrial waste in deep wells; a preliminary appraisal. Technical Bulletin No. 49. Ottawa, Canada, Inland Waters Branch, Department of the Environment, 1971.

261. Lessing, P., and R. S. Reppert. Geological considerations of sanitary landfill site evaluations. 2d ed. Environmental Geology Bulletin No. 1. [Morgantown], West Virginia Geological and Economic Survey, 1972. 34 p.

262. Geraghty and Miller, Inc. Ground-water contamination: an explanation of its causes and effects. Port Washington, N.Y., Water Information Center, May 1972. 15 p.

263. Recycling sludge and sewage effluent by land disposal. *Environmental Science & Technology,* 6(10):871-873, Oct. 1972.

264. Pavoni, J. L., D. J. Hagerty, and R. E. Lee. Environmental impact evaluation of hazardous waste disposal in land. *Water Resources Bulletin,* 8(6):1,091-1,107, Dec. 1972.

265. Kuo, C. H. Pressure behavior in subsurface disposal of liquid industrial wastes. *Water Pollution Control Federation Journal,* 44(12):2,325-2,333, Dec. 1972.

266. Winton, J. M. CW report: plant sites. *Chemical Week,* 111(15):35-50, 52, 54, 56, Oct. 11, 1972.

267. Kreplick, R., W. Litsky, and H. B. Gunner, *eds.* Proceedings of Regionalized Solid Waste Management, Technical Guidance Center for Environmental Quality, Newton, June 1-2, 1972. Amherst, University of Massachusetts. 216 p.

268. Subsurface water pollution; a selective annotated bibliography. Part 1. Subsurface waste injection. Washington, U.S. Environmental Protection Agency, Mar. 1972. 156 p.

269. Subsurface water pollution; a selective annotated bibliography. Part II. Saline water intrusion. Washington, U.S. Environmental Protection Agency, Mar. 1972. 161 p.

270. Subsurface water pollution; a selective annotated bibliography. Part III. Percolation from surface sources. Washington, U.S. Environmental Protection Agency, Mar. 1972. 162 p.

271. Ministry of Housing and Local Government, Scottish Development Department. Disposal of solid toxic wastes. London, Her Majesty's Stationery Office, 1970. 107 p.

272. Malcolm Pirnie, Inc., Consulting Environmental Engineers. Central New York regional comprehensive solid waste management plan. v.2. Albany, New York State Department of Environmental Conservation, Oct. 27, 1971. [300 p.]

273. Fungaroli, A. A. Pollution of subsurface water by sanitary landfills. v.3. Philadelphia, Drexel Institute of Technology, 1970.

274. Ham, R. K. Large elevation landfilling for refuse disposal. *Public Works,* 101(1):92-95, Jan. 1970.

*275. Proceedings; Urban Rainfall Management Problems (Runoff, Sediment, Sanitary Landfill). Technical Report UKY 51-72-CE 16. Lexington, University of Kentucky, June 1972.

276. Otton, E. G. Solid-waste disposal in the geohydrologic environment of Maryland. Report of Investigations No. 18. Maryland Geological Survey, 1972. 59 p.

*277. Cook, T. D., *ed.* Underground waste management and environmental implications. Memoir 18. *In* Proceedings; First Symposium on Underground Waste Management and Environmental Implications, [1971]. American Association of Petroleum Geologists, and U.S. Geological Survey, 1972.

278. Planners Associates, Inc. New Jersey State solid waste management plan. New Jersey Department of Environmental Protection, Bureau of Solid Waste Management, July 31, 1970. 111 p.

279. University of Louisville. Louisville, Ky.--Ind. metropolitan region solid waste disposal study; interim report on a solid waste demonstration project; volume I; Jefferson County, Kentucky. [Cincinnati], U.S. Department of Health, Education, and Welfare, 1970. 205 p.

280. Otton, E. G. Geologic and hydrologic factors bearing on subsurface storage of liquid wastes in Maryland. Report of Investigations No. 14. Maryland Geological Survey, 1970. 39 p.

*281. Tentative guidelines for hazardous waste land disposal facilities. Supplement to Hazardous waste disposal survey--1971. California solid waste planning study. California Department of Public Health, Jan. 1972. 42 p.

*282. Hazardous waste disposal survey--1971. California solid waste planning study. California Department of Public Health, Jan. 1972.

283. Kentucky State Department of Health. Kentucky solid waste management plan status report 1970. Washington, U.S. Government Printing Office, 1971. 160 p.

*284. Recent developments in environmental law. *Boston College Industrial and Commercial Law Review,* 13(4), Mar. 1972.

285. Bosselman, F. B., and D. Callies. Quiet revolution in land use control. Council on Environmental Quality. Washington, U.S. Government Printing Office, [1972]. [391 p.]

*286. Environmental quality program status, 1 January 1972. U.S. Department of Defense. p.6, 11, 52, 67-68.

287. Swenson, G. S., S. R. Bacon, R. S. Farnham, and J. E. Paseur. Soil survey of DeKalb County, Alabama. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Sept. 1958. 108 p.

288. Harper, W. G., E. N. Poulson, and J. C. Foulger. Soil survey of the Yuma Desert area, Arizona. U.S. Department of Agriculture, Bureau of Plant Industry. Washington, U.S. Government Printing Office, Mar. 1941. 35 p.

289. Larance, F. C. Soil survey of Bradley County, Arkansas. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Apr. 1961. 66 p.

290. Retzer, J. L., R. A. Gardner, L. F. Koehler, and R. C. Cole. Soil survey of Kings County, California. U.S. Department of Agriculture, Bureau of Plant Industry and Agricultural Engineering. Washington, U.S. Government Printing Office, Oct. 1946. 102 p.

291. Isgrig, D. Soil survey of San Benito County, California. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Nov. 1969. 111 p.

292. Larsen, L. S., and J. B. Brown. Soil survey of Arapahoe County, Colorado. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Mar. 1971. 78 p.

293. Cline, A. J., C. Spears, F. Mehaffey, E. Kubin, R. Franklin, and C. Pochek. Soil survey of Delta-Montrose Area, Colorado. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, July 1967. 73 p.

294. Larsen, L. S., T. G. Baber, E. L. Wesswick, D. E. McCoy, and J. B. Harman. Soil survey of Elbert County, Colorado, eastern part. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, July 1966. 79 p.

295. Shearin, A. E., and D. E. Hill. Soil survey of Hartford County, Connecticut. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Feb. 1962. 126 p.

296. Long, D. D., and M. E. Carr. Soil survey of Jasper County, Georgia. In U.S. Department of Agriculture, Soils Bureau. Field operations, 1916. Washington, U.S. Government Printing Office. p.647-685.

297. Miller, J. T., A. E. Taylor, J. C. Mercer, O. L. Dodd, and J. L. Robison. Soil survey of Union County, Georgia. U.S. Department of Agriculture, Plant Industry, Soils, and Agricultural Engineering Bureau. Washington, U.S. Government Printing Office, 1950. 144 p.

298. Phillips, S. W., E. W. Knobel, G. L. Fuller, and J. W. Moon. Soil survey of Dooly County, Georgia. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, 1928. [34 p.]

299. Downey, C. E., and R. T. Odell. Soil survey of Montgomery County, Illinois. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Aug. 1969. 94 p.

300. Tharp, W. E., and S. R. Bacon. Soil survey of Blackford County, Indiana. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, 1928. [27 p.]

301. Jones, G. B., and J. B. Brill. Soil survey of Benton County, Indiana. U.S. Department of Agriculture, Bureau of Soils. Washington, U.S. Government Printing Office, 1917. 20 p.

302. Smith, L. R., W. J. Leighty, D. R. Kunkel, and A. T. Waincko. Soil survey of Cass County, Indiana. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Apr. 1955. 129 p.

303. Pilgrim, S. Soil survey of Pulaski County, Indiana. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Jan. 1968. 84 p.

304. Dideriksen, R. I. Soil survey of Adams County, Iowa. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, May 1963. 97 p.

305. Buckner, R. L. Soil survey of Bremer County, Iowa. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Oct. 1967. 118 p.

306. Sallee, K. H., V. L. Hamilton, C. W. McBee, and E. L. Fleming. Soil survey of Kearny County, Kansas. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Nov. 1963. 71 p.

307. Dickey, H. P., W. R. Swafford, and Q. L. Markley. Soil survey of Morton County, Kansas. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Dec. 1963. 81 p.

308. Arms, F. S., D. S. Henry, A. S. Johnson, W. R. Partin, T. G. Sparks, and O. Whitaker. Soil survey of Adair County, Kentucky. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Apr. 1964. 127 p.

309. Weisenberger, B. C., R. L. Blevins, and D. M. Hersh. Soil survey of Bath County, Kentucky. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Sept. 1963. 126 p.

310. Matthews, E. D. Soil survey of Carroll County, Maryland. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Oct. 1969. 92 p.

311. Otton, E. G. Solid-waste disposal in the geohydrologic environment of Maryland. Report of Investigations No. 18. Maryland Geological Survey, 1972. 59 p.

312. Mott, J. R., and D. C. Fuller. Soil survey of Franklin County, Massachusetts. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Feb. 1967. 204 p.

313. Pregitzer, K. E. Soil survey of Muskegon County, Michigan. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Oct. 1968. 89 p.

314. Arneman, H. F. Soils of Minnesota. Minnesota University, Agricultural Extension Service, Extension Bulletin 278. [St. Paul], 1963. 7 p.

315. Edwards, R. J. Soil survey of Wright County, Minnesota. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, June 1968. 140 p.

316. Milbrandt, A. C., and L. B. Hale. Soil survey of Pike County, Mississippi. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Apr. 1968. 62 p.

317. Chugg, J. C., G. W. Anderson, D. L. King, and L. H. Jones. Soil survey of Eddy area, New Mexico. U.S. Department of Agriculture, Soil Conservation Service, Washington, U.S. Government Printing Office, Mar. 1971. 82 p.

318. Cline, M. G. Soils and soil associations of New York. rev. ed. Cornell Extension Bulletin 930. Ithaca, New York State College of Agriculture, Jan. 1970. 64 p.

319. Sweet, A. T., and W. Secor. Soil survey of Ulster County, New York. U.S. Department of Agriculture, Bureau of Plant Industry. Washington, U.S. Government Printing Office, June 1940. 52 p.

320. Pearson, C. S., D. G. Greenleaf, H. R. Adams, and W. Neely. Soil survey of Wyoming County, New York. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, Mar. 1938. 45 p.

321. Latimer, W. J., M. Howard, Jr., G. Gibbs, W. Huff, and C. S. Pearson. Soil survey of Onondago County, New York. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, Apr. 1938. 78 p.

322. Jurney, R. C., and W. A. Davis. Soil survey of Montgomery County, North Carolina. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, 1930. 34 p.

323. Seago, J. B., M. R. Wright, C. H. Wiesner, and R. S. E. Smith. Soil survey of Wells County, North Dakota. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, June 1970. 84 p.

324. Matanzo, F., K. L. Stone, R. D. Thompson, and K. H. Wenner. Soil survey of Delaware County, Ohio. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, July 1969. 71 p.

325. Baker, F. J., R. L. Meeker, and N. Holowaychuk. Soil survey of Paulding County, Ohio. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Oct. 1960. 95 p.

326. Culver, J. R., W. R. Bain, and B. G. Baggett. Soil survey of Kay County, Oklahoma. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Dec. 1967. 86 p.

327. Leighty, W. J. Soil survey of Deschutes area, Oregon. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Dec. 1958. 103 p.

328. Higbee, H. W., S. R. Bacon, R. T. A. Burke, A. L. Patrick, *et al.* Soil survey of Huntingdon County, Pennsylvania. U.S. Department of Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering. Washington, U.S. Government Printing Office, Dec. 1944. 146 p.

329. Simmons, C. S., C. H. Atkinson, and L. A. Brown. Soil survey of Wayne County, Pennsylvania. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, Apr. 1938. 31 p.

330. Camp, W. J. Soil survey of Spartanburg County, South Carolina. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Apr. 1968. 80 p.

331. True, J. C., J. F. Campbell, E. P. Davis, and D. L. Montgomery. Soil survey of Giles County, Tennessee. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Mar. 1968. 69 p.

332. Elder, J. A., E. K. Yates, I. P. Epley, and L. E. Odom. Soil survey of Marion County, Tennessee. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Apr. 1958. 88 p.

333. Mowery, I. C., and H. Oakes. Soil survey of Cherokee County, Texas. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Mar. 1959. 65 p.

*334. Geib, H. V., T. M. Bushnell, and A. H. Bauer. Soil survey of Harris County, Texas. U.S. Department of Agriculture. Washington, U.S. Government Printing Office, 1928. 50 p.

335. Beck, M. W., H. W. Higbee, and R. M. Marshall. Soil survey of Cass County, Texas. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, Feb. 1937. 30 p.

336. Porter, H. C., J. H. Petro, C. S. Coleman, E. F. Henry, C. I. Rich, and H. H. Bailey. Soil survey of Fluvanna County, Virginia. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Mar. 1958. 178 p.

337. Petro, J. H., C. S. Coleman, E. F. Henry, H. C. Porter, T. R. Watkins, W. J. Meyer, and A. J. Vessel. Soil survey of Fauquier County, Virginia. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Aug. 1956. 231 p.

338. Fowler, R. H., and A. O. Ness. Soil survey of Lewis County, Washington. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Dec. 1954. 130 p.

339. Strahorn, A. T., E. J. Carpenter, W. W. Weir, S. Ewing, *et al.* Soil survey (reconnaissance) of the Columbia Basin Area. U.S. Department of Agriculture, Bureau of Chemistry and Soils. Washington, U.S. Government Printing Office, 1929. 55 p.

340. Haszel, O. L. Soil survey of Walworth County, Wisconsin. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, Feb. 1971. 107 p.

341. Klingelhoets, A. J. Soil survey of Iowa County, Wisconsin. U.S. Department of Agriculture, Soil Conservation Service. Washington, U.S. Government Printing Office, July 1962. 101 p.

*342. Agricultural Experiment Stations of the Western Land Grant Universities and Colleges Staff. Soils of the Western United States. Pullman, Washington State University, 1964. 69 p.

343. U.S. Department of Commerce. Environmental Science Services Administration. Climatic atlas of the United States. Washington, U.S. Government Printing Office, June 1968. 80 p.

344. Holzworth, G. C. Mixing heights, wind speeds, and potential for urban air pollution throughout the contiguous United States. [Washington], U.S. Environmental Protection Agency, Jan. 1972. 118 p. [Distributed by National Technical Information Service, Springfield, Va., as PB 207 103.]

345. Thom, H. C. S. Tornado probabilities. Monthly Weather Review, 91(10/12):730-736, Oct.-Dec. 1963.

346. National Oceanic and Atmospheric Administration. Climatological data; national summary, annual. v.21. no.13. Washington, U.S. Government Printing Office, 1970. 104 p.

347. National Oceanic and Atmospheric Administration. Climatological data; annual summary [for various States]. Washington, U.S. Government Printing Office.

348. Transportation of dangerous goods. New York, United Nations, 1970. 4 v.

349. U.S. Congress. House. Toxic substances control act; hearings before the Subcommittee on Commerce and Finance of the Committee on Interstate and Foreign Commerce, 92d Cong., 2d Sess., May 18 and 23, 1972. Washington, U.S. Government Printing Office. 199 p.

350. Escape and spillage of hazardous materials and vapors from motor carriers. v.1. Bethesda, Booz-Allen Applied Research, Inc., Nov. 1967. 208 p. [Distributed by National Technical Information Service, Springfield, Va., as PB 178 182.]

351. Winton, J. W. CW report: plant sites. Chemical Week, 111(15):35-50, 54, 56, Oct. 11, 1972.

352. A study of transportation of hazardous materials. Washington, National Academy of Sciences--National Research Council, May 1969.

353. Special study; risk concepts in dangerous goods transportation regulations. Washington, National Transportation Safety Board, 1971. 35 p. [Distributed by National Technical Information Service, Springfield, Va., as NTSB-STS-71-1.]

354. Booz, Allen Applied Research, Inc. A study of hazardous waste materials, hazardous effects, and disposal methods. U.S. Environmental Protection Agency Contract No. 68-03-0032. [Bethesda, Md.], June 30, 1972. 3 v.

*355. Hazardous waste disposal program. Monthly Reports. Redondo Beach, Calif., TRW Systems Group, 1972.

356. Committee on Hazardous Materials. Evaluation of the hazard of bulk water transportation of industrial chemicals; a tentative guide. Washington, National Academy of Sciences, 1970. 25 p.

357. Leimkuhler, F. F. Trucking of radioactive materials; safety vs. economy in highway transport. Baltimore, Johns Hopkins Press, 1963. 156 p.

358. Austin, M. E. Land resource regions and major land resource areas. rev. ed. U.S. Department of Agriculture, Agriculture Handbook 296. Washington, U.S. Government Printing Office, Mar. 1972. 82 p.

359. Dee, N., J. K. Baker, N. L. Drobny, K. M. Duke, and D. C. Fahringer. Environmental evaluation system for water resource planning; final report. Columbus, Battelle Columbus Laboratories, Jan. 31, 1972. 205 p.

360. Odum, E. P. Fundamentals of ecology. 3d ed. Philadelphia, W. B. Saunders Company, 1971. 574 p.

361. Shelford, V. E. The ecology of North America. Urbana, University of Illinois Press, 1963. 610 p.

362. Blood, M. R., and C. L. Hulin. Alienation, environmental characteristics, and worker responses. Journal of Applied Psychology, 51(3):284-290, June 1967.

363. Fishbein, M. A behavior theory approach to the relations between beliefs about an object and the attitude toward the object. In M. Fishbein, ed. Readings in attitude theory and measurement. New York, John Wiley & Sons, Inc., 1967. p.389-400.

364. Herzberg, F. Job attitudes: review of research and opinion. Psychological Service of Pittsburgh, 1957. 279 p.

365. Herzberg, F., B. Mausner, and B. B. Snyderman. The motivation to work. New York, John Wiley, Inc., 1959. 157 p.

366. Hulin, C. L., and M. R. Blood. Job enlargement, individual differences, and worker responses. Psychological Bulletin, 69(1):41-55, Jan. 1968.

367. Lawler, E. E. Pay and organizational effectiveness: a psychological view. New York, McGraw-Hill Book Company, 1971. 318 p.

368. Lawler, E. E., and J. L. Suttle. A causal correlational test of the need hierarchy concept. Organizational Behavior and Human Performance, 7(2):265-287, Apr. 1972.

369. Maier, N. R. F. Psychology in industry; a psychological approach to industrial problems. 2d ed. Boston, Houghton, Mifflin Company, 1955. 678 p.

370. Maslow, A. H. Motivation and personality. New York, Harper and Row, Publishers, 1954. 411 p.

371. Porter, L. W., and E. E. Lawler. Managerial attitudes and performance. Homewood, Ill., R. D. Irwin, 1968. 209 p.

372. Sheldon, E. B., and K. C. Land. Social reporting for the 1970's; a review and programmatic statement. Policy Sciences, 3:137-151, 1972.

373. Smith, P. C., L. M. Kendall, and C. L. Hulin. The measurement of satisfaction in work and retirement; a strategy for the study of attitudes. Chicago, Rand McNally & Company, 1969. 186 p.

374. Turner, A. N., and P. R. Lawrence. Industrial jobs and the worker; an investigation of response to task attributes. Boston, Harvard University, Graduate School of Business Administration, Division of Research, 1965. 117 p.

375. Vroom, V. H. Work and motivation. New York, John Wiley, Inc., 1964. 331 p.

376. Webb, E. J. Unobtrusive measures; nonreactive research in the social sciences. Chicago, Rand McNally & Company, 1966. 225 p.

377. Wood, M. T. Some determinants and consequences of power distribution in decision-making groups. Dissertation Abstracts, 31(12):7663B-7664B, June 1971. [Thesis distributed by University Microfilms, Ann Arbor, Mich., as 71-15-002.]

378. National Industrial Pollution Control Council. Waste disposal in deep wells; Sub-council report. Washington, U.S. Government Printing Office, Feb. 1971. 20 p.

379. Heckard, J. Deep well injection of liquid wastes. Engineering Bulletin No. 35. Los Angeles, Dames & Moore, 1970. 6 p.

*380. Personal communication. G. Melickian, Dames & Moore, to A. Lee, TRW Systems, Apr. 19, 1972.

381. Bradshaw, R. L., J. J. Perona, J. O. Blomeke, and W. J. Boegly, Jr. Evaluation of ultimate disposal methods for liquids and solid radioactive wastes, VI: disposal of solid wastes in salt formations. Oak Ridge, Tenn., Oak Ridge National Laboratory, May 1968. 93 p. [Distributed by National Technical Information Service, Springfield, Va., as ORNL-3358.]

382. Siting of fuel reprocessing plants and waste management facilities. Oak Ridge National Laboratory, Tenn., July 1970. 415 p. [Distributed by National Technical Information Service, Springfield, Va., as ORNL-4451.]

383. Bendixsen, C. L., and G. E. Lohse. Storage facilities for radioactive calcined waste solids at the Idaho chemical processing plant. Idaho Falls, Idaho Nuclear Corporation, July 1968. 31 p. [Distributed by National Technical Information Service, Springfield, Va., as IN-1155.]

384. Regan, W. H., ed. Proceedings of the Symposium on the Solidification and Long-Term Storage of Highly Radioactive Wastes, Richland, Wash., Feb. 14-18, 1966. Washington, U.S. Atomic Energy Commission. 900 p. [Distributed by National Technical Information Service, Springfield, Va., as CONF-66080.]

385. Dunn, C. S., D. Geary, O. Gilliland, and J. Wyrick. Feasibility of permanent storage of solid chemical waste in subsurface salt deposits. Tulsa, Okla., Fenix and Scission, Inc., Oct. 1971. (Restricted distribution.)

386. Morton, R. J. Land burial of solid radioactive wastes: study of commercial operations and facilities. Washington, U.S. Atomic Energy Commission, 1968. 133 p. [Distributed by National Technical Information Service, Springfield, Va., as WASH-1143.]

*387. Pavoni, J. L., D. J. Hagerty and R. E. Lee. State of the art of land disposal of hazardous wastes. Presented at Seventh American Water Resources Conference, Washington, Oct. 24-28, 1971.

388. Sorg, T. J., and H. L. Hickman, Jr. Sanitary landfill facts. Public Health Service Publication No. 1792. 2d ed. Washington, U.S. Government Printing Office, 1970. 30 p.

*389. Tentative guidelines for hazardous waste land disposal facilities. Supplement to Hazardous waste disposal survey--1971. California solid waste planning study. California Department of Public Health, Jan. 1972. 42 p.

390. Gunnerson, C. G. An appraisal of marine disposal of solid wastes off the west coast: a preliminary review and results of a survey. [Cincinnati], U.S. Department of Health, Education, and Welfare, 1970. 32 p.

391. Smith, D. D., and R. P. Brown. Ocean disposal of barge-delivered liquid and solid wastes from U.S. coastal cities. Washington, U.S. Government Printing Office, 1971. 119 p.

*392. Smith, D. D., and R. P. Brown. Deep sea disposal of liquid and solid wastes. Industrial Water Engineering, U.S. Environmental Protection Agency, Sept. 1970.

393. U.S. Congress. House. Ocean disposal of unserviceable chemical munitions; hearings before the Subcommittee on Oceanography of the Committee on Merchant Marine and Fisheries, 91st Cong., 2d Sess., Aug. 3-7, 1970. Washington, U.S. Government Printing Office. 342 p.

394. Council on Environmental Quality. Ocean dumping, a national policy; a report to the President. Washington, U.S. Government Printing Office, 1970. 45 p.

*395. Reed, W. F., Jr. Assessment of the environmental effects of past deep water dumping operations. Thirteenth Annual Explosives Safety Seminar Minutes, Armed Forces Explosives Safety Board, San Diego, Sept. 1971. 257 p.

396. Witt, P. A., Jr. Disposal of solid wastes. *Chemical Engineering,* 78(22):62-78, Oct. 4, 1971.

397. U.S. Congress. House. Dumping of waste material; hearings before the Subcommittee on Fisheries and Wildlife Conservation of the Committee on Merchant Marine and Fisheries, 91st Cong., 2d Sess., July 27-28, Sept. 30, 1970. Washington, U.S. Government Printing Office. 296p.

398. Hood, D. W., B. Stevenson, and L. M. Jeffrey. Deep sea disposal of industrial wastes. *Industrial and Engineering Chemistry,* 50(6):885-888, June 1958.

399. Radioactive waste disposal into Atlantic and Gulf coastal waters. National Research Council Publication 655. Washington, National Academy of Sciences, 1959. 37 p.

400. Considerations on the disposal of radioactive wastes from nuclear-powered ships into the marine environment. National Research Council Publication 658. Washington, National Academy of Sciences, 1959. 52 p.

401. Disposal of low-level radioactive waste into Pacific coastal waters. National Research Council Publication 985. Washington, National Academy of Sciences, 1962. 87 p.